Soquel Demonstration State Forest
California Department of Forestry and Fire Protection
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Fisheries Management Plan

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INTRODUCTION

The Soquel Demonstration State Forest (SDSF) was authorized in 1987 with the passage of California State Assembly Bill 1965 (AB 1965). The bill described SDSF as "...an intensively managed, multifacted research forest which is representative of forest activities." Like all demonstration state forests in California, SDSF is based upon the fundamental goals of research and education, and the demonstration of sustained-yield forest management. Management activities at SDSF are meant to demonstrate the compatibility of forest management with the conservation of natural resources. These resources include wildlife, fisheries, vegetation, and soil.

In 1990, when the California Department of Forestry and Fire Protection (CDF) assumed management of the forest, SDSF managers prepared to carry out these responsibilities. In 1993, SDSF managers, with the advice of an advisory committee, local resource professionals and input from the public, completed a Draft General Forest Management Plan (GFMP). The GFMP outlines how AB 1965 will be carried out in SDSF, together with pre-existing State Forest regulations. The GFMP provides direction for more specific planning of management activities. This Fisheries Management Plan is based upon the fisheries management guidelines in the GFMP, and describes in detail SDSF's management strategy for fisheries. This plan will be used to guide fisheries research, monitoring, and restoration. It will also provide for the protection of fisheries resources in planning forest activities.

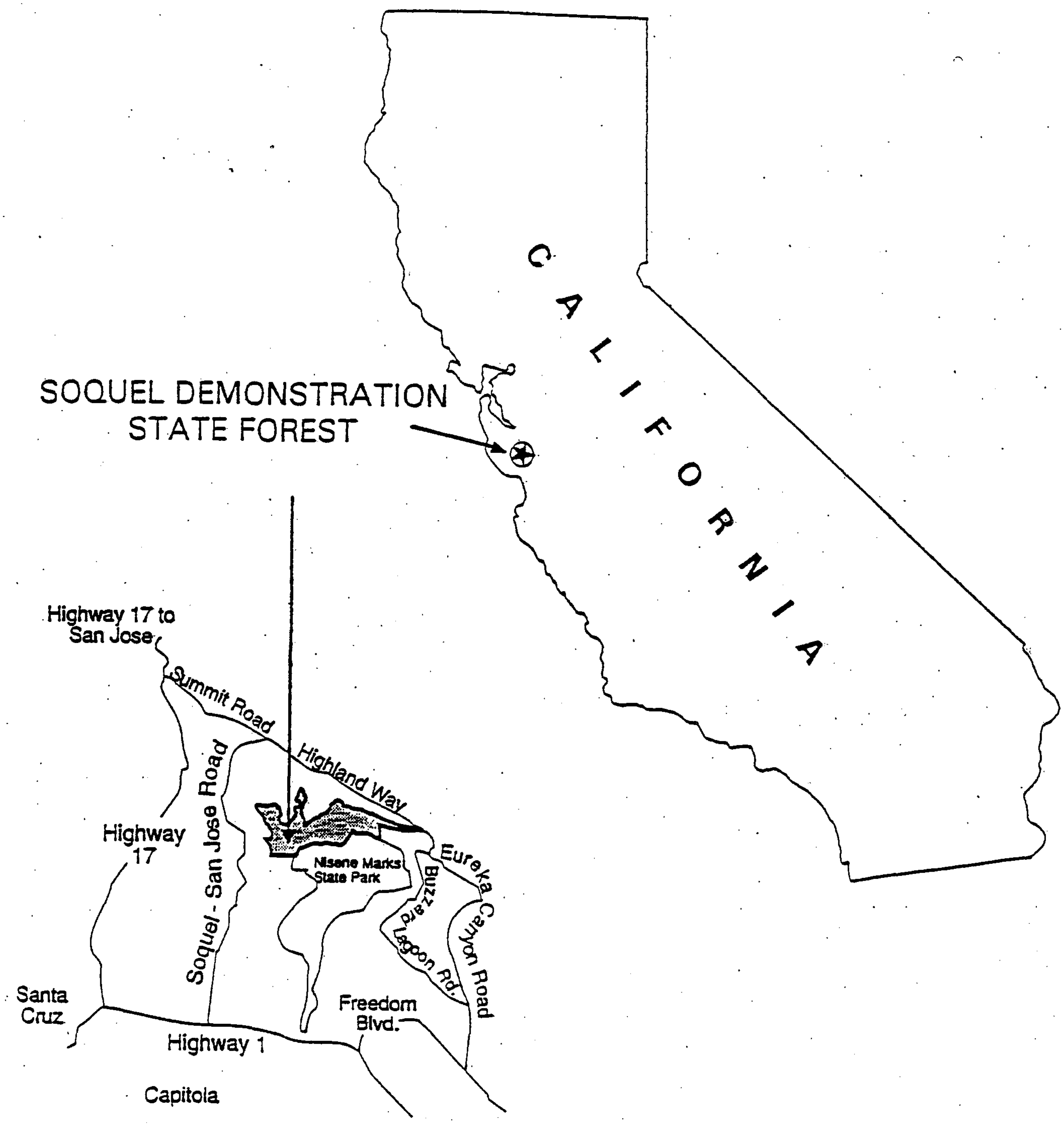
The Area

Soquel Demonstration State Forest (SDSF) is located in Santa Cruz County, on the East Branch of the Soquel Creek watershed. Soquel Creek drains into the Monterey Bay near the city of Capitola. A sandbar is constructed annually across the mouth of the creek at seasonal low flows, creating the Capitola Lagoon. The sandbar is removed before the rainy season, allowing for fish migration. The East Branch comprises approximately 32% of the entire Soquel Creek drainage. The 2,681 acres in SDSF cover approximately 30% of the East Branch drainage (Map 1).

Nine miles of fish-bearing stream flow through SDSF. The East Branch of Soquel Creek (5.5 miles) includes a 15 foot drop called Ashbury Falls. Fish are found upstream of Ashbury Falls, but it is not known whether the falls block upstream migration. Tributaries Amaya Creek (2 miles) and Fern Gulch (1.5 miles) provide additional aquatic habitat, but it is unknown how much of this habitat is accessible to fish. The East Branch and Amaya Creek are considered to be the main fish-bearing streams in SDSF (Map 2).

The geology of the East Branch drainage is generally unstable. It is largely underlain by highly weathered and easily erodible fine-grained sedimentary rock, which is prone to mass-wasting events. The San Andreas fault zone underlies the forest, following the East Branch in SDSF to Ashbury Gulch, forming Ashbury Falls. A Geologic Assessment of SDSF (Manson & Sowma-Bawcom, 1992) emphasized that seismic activity along the fault combined with flood flows in the creek commonly trigger small landslides in and near stream channels. This type of mass

Map 1
Locator Map for SDSF



wasting is the main cause of sedimentation in SDSF creeks. Surface erosion from the loamy soils is small in comparison (Manson & Sowma-Bawcom, 1992).

The Watershed Assessment for SDSF (Cafferata and Poole, 1993) confirmed that stream channel stability depends on the degree of geological instability of the area. Stability ratings according to the Pfankuch scale ranged from "medium poor" to "high fair" (Cafferata and Poole, 1993). Overall, Amaya Creek showed a higher degree of instability than the East Branch. One hundred percent of Amaya Creek was designated as having "poor" stability, whereas the majority (67%) of the East Branch was found to have "fair" stability (Cafferata and Poole, 1993).

The climate of the Santa Cruz mountains is Mediterranean, with dry, warm summers and cool, wet winters. Precipitation occurs mostly between November and April and ranges from 36-46 inches in SDSF. Stream discharge of Soquel Creek at the USGS station located in the city of Soquel has averaged 7,446 cubic feet per second (cfs) between July 1987 and June 1993, but often varies by several hundred percent during the year. A stream gauge is located on the East Branch downstream of SDSF, approximately one-quarter mile downstream from the forest. The average flow at that meter has been 2,364 cfs also between 1987 and 1993.

Vegetation in SDSF is predominantly coastal redwood forest, with mixed evergreen hardwood forest dominating in drier areas. Riparian vegetation in SDSF is dominated by white alder (Alnus rhombifolia), coast redwood (Sequoia sempervirens), and various types of willow (genus Salix) (Holland et al., 1992).

Local Species

The dominant fish species on the property is steelhead trout (Oncorhynchus mykiss). In recent years, Coho salmon (Oncorhynchus kisutch) populations have dwindled in all creeks south of San Francisco Bay, including Soquel Creek (Hope, 1993). Surveys and incidental sightings indicate that there is probably no stable population of Coho in Soquel Creek.

Other fish species observed in Soquel Creek include: prickly sculpin (Cottus asper), coast-range sculpin (Cottus aleuticus), three-spine stickleback (Gasterosteus aculeatus), California roach (Lavinia symmetricus), and Sacramento sucker (Catostomas occidentalis) (Harvey and Stanley Associates, 1982). The tidewater goby (Eucyclobius newberryi), a species of special concern at the state level, and an endangered species at the Federal Level, can be found at the mouth of Soquel Creek. Species sighted in SDSF include: the Pacific Lamprey (Lampetra tridentata) and the California newt (Taricha torosa).

Water Use

Water is in demand by private residences and businesses alike. Historically, water users had free access to water from Soquel Creek. Adjudication procedures for the distribution of water rights were established in 1973 to curb overdrafting. In 1974, the Department of Fish and Game established a protocol of minimum seasonal flows on Soquel Creek in an effort to protect fish habitat. Despite these efforts to regulate water use, overdrafting of water has continued to be a problem, and the creek has been dewatered in some places during dry years. Disputes over water rights have been so common that the State Water Resource Control Board ruled that a watermaster was needed to arbitrate water rights issues. However, no watermaster has yet been appointed (P. Anderson, pers.comm. 1995). Recreational fishing is prohibited on the East Branch by California Fish and Game Commission regulations.

Land Use & Management Activities

The Soquel Creek watershed sustains many land uses, including residential and business development, agriculture, granite quarrying and forest management. Granite quarrying takes place downstream from SDSF in the East Branch drainage, at Olive Springs Quarry. Upstream from SDSF, the main land uses are residential and forest management.

Of all the activities in SDSF since its establishment in 1990, road use and recreation have had the highest potential for adverse impact to streams. Actions have been taken to reduce potential impact. Erosion from trails and roads has been reduced through renovation and improvement. Private vehicles are prohibited on forest roads, and public access is limited to foot, horse and bicycle traffic.

SDSF's General Forest Management Plan calls for periodic timber harvesting. The first harvest is scheduled for the summer of 1995. Fisheries resources are of special concern during timber harvests. Decreases in vegetation can cause quantitative changes in flow and change flow timing. Increased sedimentation can degrade habitat by filling pools and infiltrating spawning gravels. Similar impacts are also caused by natural instability, which is of greater significance in SDSF. The Watershed Assessment of 1993 concluded that timber operations are unlikely to have a severe impact on the watershed, relative to its severe geological instability (Cafferata and Poole, 1993).

The effects of timber harvesting and other forest activities can be minimized if fisheries management is integrated into forest management planning. SDSF management has already taken steps to incorporate fisheries into forest management. It plans to "protect stream channels, streambanks, and riparian zones" and to establish late-succession management areas along all fish-bearing streams (CDF, 1993a). Efforts will be made to improve fish habitat where possible. In addition, SDSF will continue to coordinate fisheries management with other forest activities, according to the management guidelines described below.

MANAGEMENT GOALS

1) SDSF will protect and enhance habitat for existing fish populations. Steelhead trout, the dominant aquatic species in SDSF, will be the focus of fisheries management. SDSF will monitor to determine if, over time, other species, such as Coho salmon benefit from SDSF fisheries enhancements.

2) SDSF fisheries management will demonstrate that fisheries habitat enhancement is compatible with other forest activities.

3) A monitoring plan will be implemented to gather habitat and population information. Guidelines for research will be described in the Planned Actions section below.

4) Fisheries research and management will be integrated into forest-wide educational efforts.

5) SDSF staff will coordinate with other government agencies, local schools, universities and volunteers to encourage and achieve research goals.

6) Habitat maintenance and enhancement efforts will focus on prevention of habitat degradation through the planning of forest activities to avoid impacts on fish habitat quality.

7) Habitat restoration will be done, when possible, to improve conditions of fisheries.

8) SDSF staff will support and participate in watershed-wide cooperative restoration efforts.

STEELHEAD TROUT

Demographics

Steelhead once inhabited coastal streams from the Bering Sea to Baja California. Worldwide and local populations have declined rapidly since the 1950's due to degradation and loss of habitat, as well as overfishing (Barnhart, 1986). Currently, steelhead range from the Northern border of California to just north of Los Angeles, on the Ventura River (Barnhart, 1986). On Soquel Creek, steelhead are thought to inhabit the length of the main channel, and all major tributaries. One population survey compared the density of steelhead on Soquel Creek in 1981 to the density in 1994, and found that there was little change over the past 13 years. In 1981 the density of steelhead was 3.9 fish per 10 feet, and in 1994 the density was 4.1 fish per 10 feet (D.W. Alley and Associates, 1994). This study concluded that steelhead populations on Soquel Creek are not declining. Another recent study of three other creeks in Santa Cruz County concluded that steelhead populations in the general area do not seem in danger of continued decline (Smith, 1994). Although these studies give an encouraging prognosis for steelhead, current populations are well below historical estimates.

Steelhead Biology and Habitat Requirements

Habitat requirements for steelhead vary with life-stage and season. Because of this variation, a variety of habitat conditions must exist to accommodate steelhead. Streams with a diversity of habitats including a pool to riffle ratio of approximately 1:1, an abundance of cover, and a lack of sedimentation are hospitable to steelhead in all life-stages.

Riparian vegetation and aquatic macroinvertebrate populations are also indicative of fish habitat quality. Immature insects, the main food source for juvenile steelhead, typically feed on instream decomposing leaf litter which falls from streamside plants.

Adult steelhead migrate inland from the ocean to spawn when peak flows facilitate upstream movement. On Soquel Creek, upstream migration generally occurs between January and April.

During extended dry periods, when the creek is especially low, timing of peak winter flows can determine the successful migration of adult fish (Harvey and Stanley Associates, 1982). Spawning begins once migration is accomplished, and requires a different set of specific conditions. Spawning and egg incubation are most successful in gravely substrate, where water movement is sufficient to oxygenate eggs, but water velocity is not so great as to disturb them (Behnke, 1992). These conditions are most often present at pool-tails (CDFG, 1994a).

After they hatch and emerge from the stream substrate, juvenile fish gather in shallow flatwater, often at stream edges (Barnhart, 1986). Protective cover is especially important at this time (Harvey and Stanley, 1982; Behnke, 1992). As they mature, the fish gravitate towards riffle areas (Barnhart, 1986; Behnke, 1992). Once they have reached maturity, they may migrate downstream to the ocean, or they may remain inland for up to three years in freshwater before migrating (Shapovalov and Taft 1954). Fish that never migrate out to sea are termed resident rainbow trout. Overwintering habitat is especially important for resident fish and fish that do not migrate to the ocean. Deep pools with plenty of cover provide optimum overwintering habitat (Behnke, 1993).

POTENTIAL CAUSES OF HABITAT DEGRADATION

Episodic or chronic watershed disturbances can degrade steelhead habitat in various ways. Vegetation loss and increased sedimentation are considered to be major factors in steelhead habitat degradation. Both can be caused by natural or human forces. Large-scale vegetation loss can affect steelhead by changing the flow regime of a watershed. Changes in flow timing or quantity may disrupt the progression of the steelhead life-cycle, or lead to adverse changes in water temperature. Eroded sediment can physically degrade steelhead spawning habitat. Fine sediment can clog inter-gravel spaces in spawning substrate, reduce oxygen flow to eggs and abrade their surfaces (Barnhart, 1986).

Natural Disturbance

On the East Branch of Soquel Creek, natural disturbance is high due to the inherent instability of the area. Records show that the area has undergone at least ten significant earthquakes in the last 175 years. Effects of the 1906 earthquake in SDSF are well documented (Dillon, 1992). It is speculated that the 15 foot drop at Ashbury Falls was created during that event. Many landslides resulted from the movement as well. The shaking caused trees throughout the forest to tilt, lose limbs, or fall. Several leaning trees dating from the 1906 earthquake can still be found in SDSF. The 1989 Loma Prieta earthquake caused similar damage, including landsliding. Fissures in the earth throughout the Forest are visible indicators of this event. Stream bank damage in the East Branch and Amaya Creeks was characterized as "severe" (Manson & Sowma-Bawcom, 1992).

Record storms have also contributed to land failures in the Forest. In particular, storms of 1955, 1982, 1983, 1986 and 1995 were severe enough to cause massive bedload movement in the creeks. The effects of the 1994/95 winter storm season were observed by SDSF staff. Considerable movement of sediment and debris occurred in the East Branch, changing debris jam locations, and causing the stream to change course in some places.

Human Disturbance

Human activities can also cause habitat-damaging disturbances. However, these disturbances can be prevented and mitigated through careful planning and execution of management activities. Of all management activities in SDSF, road work and timber harvesting have the greatest potential to damage steelhead habitat.

There is evidence that timber was harvested in the area by indigenous people from prehistoric times (Dillon, 1992). During Spanish colonization, timber harvesting and sales grew into a lucrative industry, and attracted other European colonists over time. A "lumber boom" took place in the mid-1800's that coincided with the population increase caused by the California Gold Rush. Since then, the timber industry has continued to thrive in Santa Cruz county.

Documented timber harvesting on the SDSF property began in the 1880's, with the projects of F. A. Hihn. Hihn harvested in SDSF along Sulphur Springs and Hihn's Mill roads until 1924. The Monterey Bay Redwood Company harvested heavily and consistently from 1926 to 1942. During this time, much of the East Branch drainage, including the Amaya Creek and Fern Gulch drainages, was clear cut. According to J. Harris Jr., a timber operator at the time, the entire drainage had been logged out by 1946. The CHY company selectively logged residual old-growth on and near SDSF property during the late 1960's and early 1970's, taking approximately 4 million board feet. One third of this total was taken from what is now SDSF (Dillon, 1992). In 1979 Pelican Timber Company bought the land and harvested redwood in both the East Branch and Amaya Creek drainages until 1984. The Nature Conservancy took over the interim stewardship of the Soquel Forest in 1988. In 1990, management of SDSF was assumed by CDF.

Timber harvests prior to 1973 seem to have had a lasting impact on conditions in SDSF streams (Cafferata and Poole, 1993). In 1973, with the passage of the modern Forest Practices Act, logging practices underwent significant revision. Clearcutting had been abolished in 1969 by Santa Cruz County ordinance. Together, the County ordinance and the Forest Practices Act minimized potentially damaging practices, and improved standards for timber harvests in Santa Cruz County.

Without proper maintenance, unpaved roads can contribute significant amounts of sediment to a stream system. In SDSF, roads are designed and maintained to drain water as effectively as possible. As on other forest roads, weak points on SDSF roads are generally associated with culverts. Undersized, unmaintained or jammed culverts can divert water onto roads, which may lead to increased erosion and road failure. In SDSF, culverts are monitored regularly during the wet season, in order to curb erosion.

The impact of recreational activities has not yet proven to be significant. However, recreation that causes excessive physical disturbance of creek channels or involves the release of gray water into creeks could damage the SDSF fishery. Such recreation will be discouraged through educational efforts, posted regulations and patrols.

THE SDSF FISHERY

Survey History

Historically, fisheries research on the East Branch of Soquel Creek has been irregular. The earliest available habitat survey, dating from 1959, found the stream to be "...an excellent steelhead stream," and "...in excellent shape for its fine pools, food, and spawning areas." (CDF, 1993b). Records indicate that the East Branch was not surveyed again until 1981, when the conditions for migration were rated as "fair" and the conditions for spawning as "poor to fair" (Harvey and Stanley, 1982). A 1982 CDFG survey, after an extremely wet winter, found the creek to be in "generally good condition" (Turner, 1982). In 1985, a CDFG field note recorded that siltation was noticeable (Marston, 1985a), and another described the habitat but did not make an evaluation (Marston, 1985b). The County of Santa Cruz sponsored a survey in 1986 that found "great fish habitat in the east Soquel ... to the bedrock falls [Ashbury Falls]" and "at least one mile of good habitat beyond the falls" (CDF, 1993b). In 1994, a systematic survey of habitat in the East Branch and Amaya Creek in SDSF was sponsored by CDF (report in appendix).

Population surveys have also been sporadic. During the 1959 survey, 11,500 fish were counted in the stream; all were steelhead trout (Schreiber and Jones, 1959). Earlier informal population surveys, conducted in 1956 and 1958, confirm the predominance of steelhead in the East Branch (CDF, 1993b). By 1973, the adult steelhead run on Soquel Creek was estimated to be just 500-1,000 fish a year (CDFG, 1973). Electrofishing was performed by Harvey & Stanley Associates in 1981 at four sites downstream from SDSF property (Harvey & Stanley Associates, 1982). They derived a range of densities of 2-13 juveniles per 10 feet of stream on the East Branch. Another electrofishing survey was performed on the East Branch by CDFG in 1988, but the results are unknown (CDF, 1993b).

Electrofishing was first done on SDSF property in 1993, when three stations on the East Branch were electrofished by CDF (Valentine, 1993; Anderson, 1993). No estimates were made of the overall population in SDSF at that time. Instead, densities were calculated for each of the stations. On the East Branch below Ashbury Falls, the combined density of steelhead at two stations was estimated to be 12.3 fish per 10 feet. CDF surveyed these two stations again in 1994, along with three other stations on the East Branch (report in appendix). D. W. Alley and Associates used data from the 1994 CDF surveys and independent field work to produce estimates for the overall densities of steelhead on Soquel Creek and its branches (D. W. Alley and Associates, 1994). These density estimates were compared to those produced by Harvey and Stanley in 1981. The 1994 report found that the density of young-of-the-year fish was 89% of the 1981 value, but the density of 1+ year old fish was 256% of the 1981 density. Alley and Associates concluded that the status of the steelhead population in the Soquel Creek watershed had not declined during that period.

More consistent study and monitoring are necessary to achieve a clearer understanding of the fisheries on the East Branch of Soquel Creek, and in SDSF in particular. The CDF surveys of 1993 and 1994 mark the beginning of organized research efforts. The habitat survey (1994) with the population surveys (1993, 1994) give a current assessment of the SDSF fishery.

The SDSF Fishery in 1994

The results of the 1994 surveys indicate the current conditions of the SDSF fishery. They **will also provide precedent** for planning future study and improvements.

Habitat

The habitat survey was conducted according to the protocol set by the Department of Fish and Game in the California Salmonid Stream Habitat Restoration Manual (Flosi and Reynolds, 1991). The stream was divided into large units called reaches, according to its channel type. Channel types were determined by assessing the stability, gradient and dominant substrate of a stretch of stream. Reaches were subdivided into habitat units, which fall into three broad categories: riffle, flatwater and pool.

Three reaches were defined on the East Branch. Reach 1 stretched from the southern boundary of SDSF to approximately 775 feet below the confluence with Amaya Creek. Reach 2 extended to the area between Fern Gulch and Ashbury Falls (see map 2). Reach 3 included the rest of the stream surveyed. Amaya Creek made up another reach from its confluence with the East Branch to the SDSF property boundary. The channel types for all of the reaches are described in detail in Table 1.

Table 1. Reaches on East Branch by channel type and percent length

Reach	Percent length	Channel Type & Description
1	13.2%	B3: "Moderate gradient; unstable rejuvenating slopes; cobble/gravel channel; source of unlimited sediment supply."
2	37.8%	C1: "Gentle gradient; cobble bed meandering channel with developed flood plain."
3	49.0%	B1: "Moderate gradient, stable, small boulder/large cobble channel."

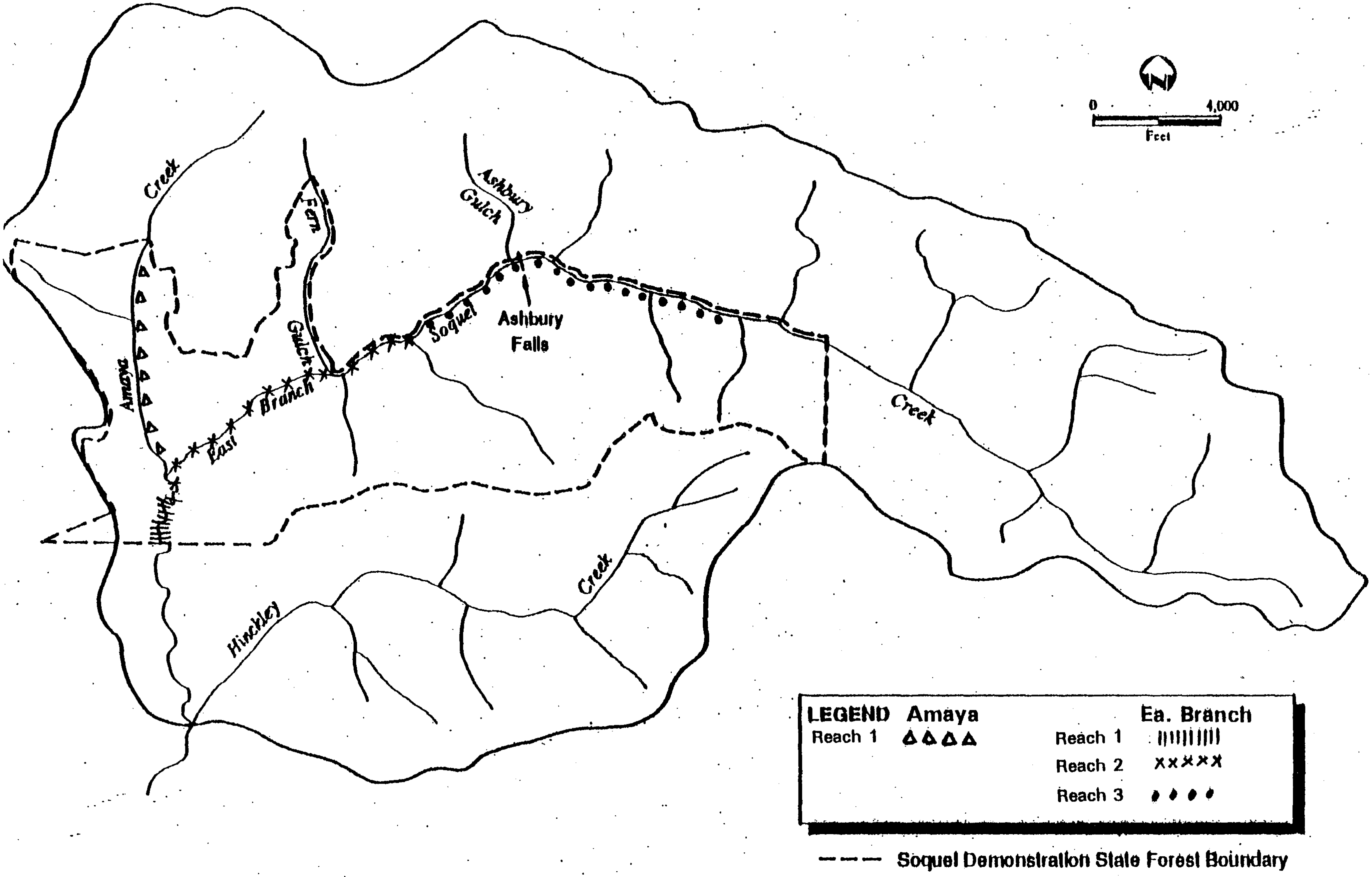
Table 2. Reaches on Amaya Creek by channel type and percent length

Reach	Percent length	Channel Type & Description
1	100%	B4: "Moderate gradient, relatively fine river terraces, unstable gravel/sand channel"

Pool to riffle ratios were found to be below the optimum 1:1 in both creeks. The disparity was particularly acute in reach 2 of the East Branch and on Amaya Creek. Pool:riffle ratios were greater than 1:1 in reaches 1 and 3 of the East Branch.

Table 3. Habitat Types by Length on the East Branch and Amaya Creek

	% riffle	% flatwater	% pool	% dry	pool:riffle
East Branch	36	35	28	1	0.78
Reach 1 (B3)	33	31	35	0	1.06
Reach 2 (C1)	43	36	20	0	**0.47**
Reach 3 (B1)	31	35	32	2	1.01
Amaya Creek	47	34	19	0	**0.44**



Jones & Stokes Associates, Inc.

Map 2

Approximate Locations of Reaches on Amaya Creek and the East Branch

Escape shelter, or cover, was found to be diverse in both creek, however, there was not enough of it. Pool habitats in both creeks had an average of 22% cover, and flatwater habitats had an average of 15% cover. Cover in riffle habitats averaged 17% on the East Branch and 13% on Amaya Creek. On the East Branch, the lack of cover was somewhat more prevalent in reach 2 than in other reaches.

Substrate conditions were mixed on both streams. Gravel predominated on the East Branch, providing good conditions for spawning and for juvenile fish. However, there was also a high instance of silt/clay substrate in pools, detracting from the otherwise good substrate conditions. Siltation was especially marked in reach 1 pools, which receive sediment from both Amaya Creek and the East Branch. Embeddedness values on the East Branch were low, indicating that spawning areas are not chronically sedimented.

Substrate conditions on Amaya Creek seem to reflect the inherent instability of the drainage. Silt/clay substrate was second only to small cobble in overall dominance. Fine sediment comprised a significant portion of substrate throughout the stream, and pools were generally shallow, perhaps because they were overburdened with sediment. Shallowness might also be attributed to underlying structure or to recent low flows. Despite the prevalence of sediment, low embeddedness at pool tails suggests that sediment has not dominated the habitat for a long period of time. The relatively clear conditions at pool tails indicated that spawning habitat was available on Amaya Creek. Patterns and sources of sedimentation in Amaya Creek will become more clear with further study and monitoring.

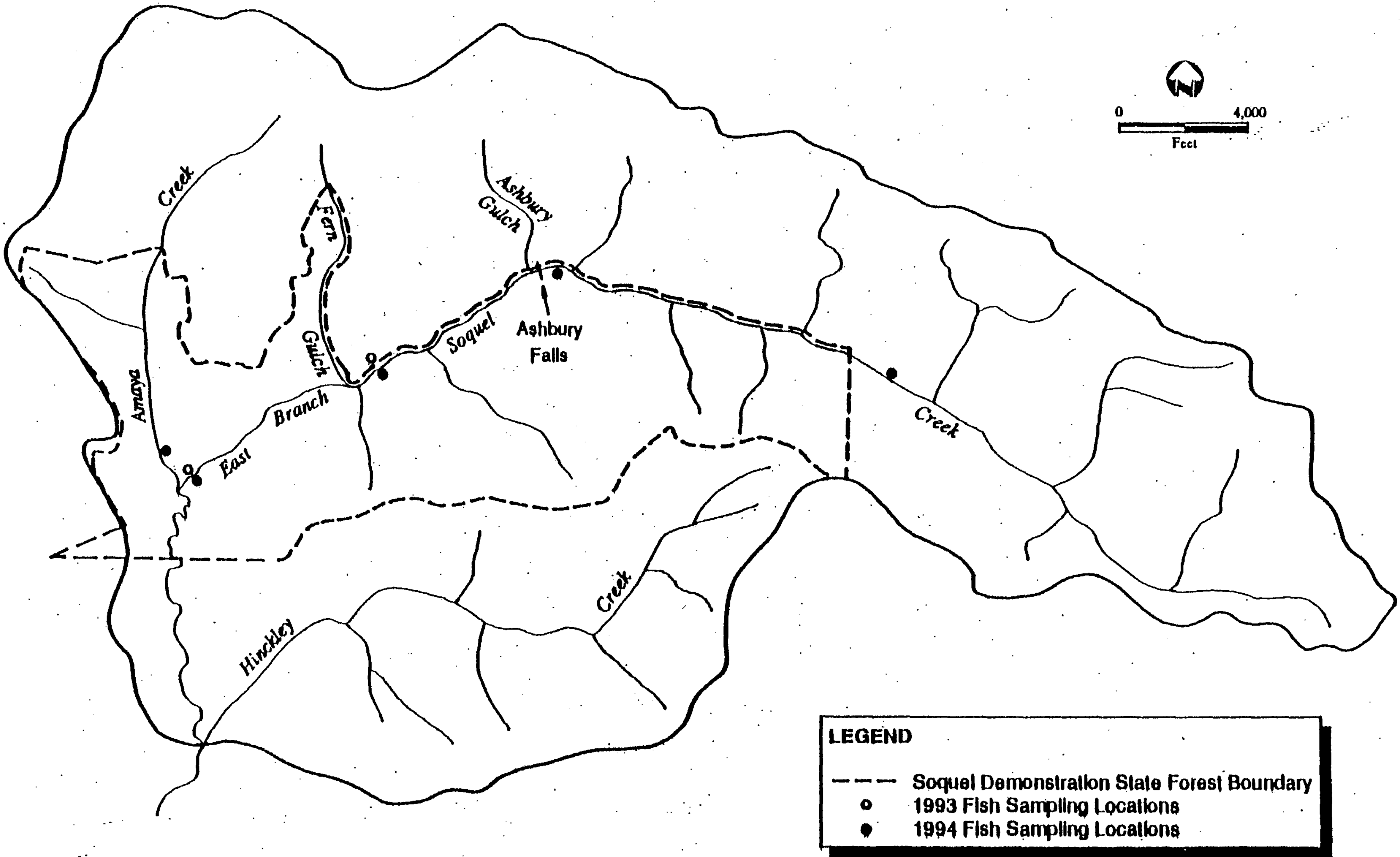
Population

Fish populations in both Amaya Creek and the East Branch were sampled in the 1994 population survey. As expected, steelhead and rainbow trout dominated the surveyed populations by a large margin. The combined density of steelhead at two stations on the East Branch below Ashbury Falls was 4.7 fish per 10 feet of stream. At the Amaya Creek station, the density of steelhead was just 0.4 fish per 10 feet of stream. The marked difference in steelhead density reflects the disparity in steelhead habitat quality indicated by the habitat survey. Four sampling stations were established in the Forest (map 3). Future sampling will take place at those stations.

PLANNED ACTIONS

Research and Monitoring

A comprehensive fisheries research program will be established which will build upon the surveys of 1993 and 1994. The program will include regular population and habitat surveys. In addition, new areas of research will be added to improve our understanding of the SDSF fishery. New areas of research will include: measurement and monitoring of sedimentation, and aquatic invertebrate population assessment. Field work will be done by CDF staff with the assistance of other agencies and volunteers. The availability of funding and of human resources will determine whether all planned actions will be accomplished.



Jones & Stokes Associates, Inc.

Map 3
Approximate Fish Sampling Locations on Amaya Creek and the East Branch

1. Fish population surveys will be performed annually for the next three years, so that a basis of five years' data may be established, including the 1993 and 1994 surveys. Subsequent surveys will take place every five years, or after every twenty-year storm or drought, whichever period is shorter. These surveys will be performed with as much consistency as possible; time-of-year, station locations, and survey procedure will be as consistent as possible from survey to survey. In future surveys, stations will be habitat-typed prior to electrofishing. This additional procedure will account for changes in habitat composition, and will enable the comparison of each station to the whole stream, based on proportional habitat composition.

Project:	Electrofishing population survey
Locations:	The 4 sampling stations established in 1994
Frequency:	Annually 1995-7, every five years thereafter
Time of year:	Fall (late August-October)
Time:	5-7 full days
Personnel:	3-5 people
Equipment:	1 electrofisher, 3 batteries, 1-2 small dip nets, 1 long-handle net, 2 seine nets, scale, rubber gloves, hip boots, measuring board, flow meter, clip-board, data sheets
Methodology:	Habitat type stations. Fish to depletion (see regression table in appendix). Habitat type each station before electrofishing. Use Microfish Program to obtain population estimates for each station. Briefly electrofish above any potential barriers encountered.

2. Formal habitat surveys of all streams in the Forest will be conducted every 10 years. Briefer, more focused surveys will be conducted as precursors to potential projects and forest management activities that may impact fish habitat.

Project:	Habitat survey
Locations:	the East Branch and Amaya Creek in SDSF boundaries
Frequency:	Every ten years, or after twenty-year storm events
Time of year:	Summer
Time:	4-5 weeks
Personnel:	2-3 people
Equipment:	50 m. tape measure, 6 ft. graduated wooden rod, thermometer, watch, clinometer, wading boots, clip board, data sheets
Methodology:	Follow 1994 methodologies as closely as possible; they are described in the California Salmonid Habitat Restoration Manual (Flosi and Reynolds, 1991).

3. Sedimentation levels will be monitored using the V-star technique (Lisle and Hilton, 1993). Levels will be measured periodically at consistent sites on the East Branch of

Soquel Creek below Ashbury Falls. The resulting data will be used to track trends in sedimentation of creek habitat.

Project:	V-star sediment survey
Locations:	One set of 10-15 pools must be located on the East Branch below Amaya Creek. If additional work is possible, another set between Amaya Creek and Fern Gulch should be surveyed.
Time of year:	Summer
Time:	2-3 days
Personnel:	2-3 people
Equipment:	2 metric measuring tapes, chaining pins, 1 stainless steel rod (1/2 inch in diameter, marked in centimeters), wading boots, clip board, data sheets
Methodology:	follow methodology as outlined in USDA Forest Service Research Note PSW-RN-414 (Hilton and Lisle, 1993), in appendix.

4. Aquatic macroinvertebrates will be sampled regularly. Because they are sensitive to a wide spectrum of stream habitat conditions, the composition of aquatic invertebrate populations is indicative of stream habitat quality. Sampling and analyzing population diversity and composition can be a useful monitoring technique when used in conjunction with other monitoring methods. SDSF will sample aquatic invertebrates according to protocol developed by the California Department of Fish and Game (CDFG, 1995).

Project:	Aquatic macroinvertebrate sampling
Location:	Sampling will take place at riffles in electrofishing stations. The two electrofishing sites on the East Branch below Ashbury Falls, and the sites on Amaya Creek are appropriate locations. Three samples will be taken at each riffle. (Note: Aquatic invertebrates sampling should be done before electrofishing, if done on the same day.)
Frequency:	Annually, 1-2 times a year
Time of year:	spring and/or fall
Time:	1 day ea.
Personnel:	1-2 people
Equipment:	D-shaped kick net, plastic collection bottles, preserving solution, wading boots, waterproof gloves, enameled pan, size 35 sieve, thermometer, forceps, 100 meter tape measure, waterproof paper, alcohol-proof pen, data sheets (w/ protocol), watershed topographic map
Methodology:	Follow the methodology in California Stream Bioassessment Procedure, 1995 (CDFG, 1995).

5. An organized approach will be adopted towards monitoring in-channel slide locations. New slides will be noted, and any changes in the severity or position of older slides will

be recorded. This information will help to locate potential areas for mitigation, and to identify areas of chronic instability.

Project:	Recording slide locations
Frequency:	incidentally
Time of year:	all times
Methodology:	Note changes in severity or position of existing slides, as well as new slides. Use the form provided ("Stream Inventory Sheet", in appendix) or a modified version. Collect notes in a central location, and track trends.

6. Stream temperature will be measured during the dry season using instream temperature monitors. Temperatures will also be monitored coincidentally during surveying efforts. Results from the permanent stations will be reviewed to track any changes.

Project:	Instream temperature monitoring
Locations:	Upstream and downstream boundaries of SDSF property. More stations will be added as resources allow.
Frequency:	annually
Time of year:	May-September
Methodology:	Install monitoring stations in May. Collect and download data in September.
Personnel:	2 people
Time:	1 day in May, 1 day in September in field. 1 day to process data.

7. Stream flows on the East Branch are currently monitored downstream from the forest by the Soquel Creek Water District. A gauge will be installed on Gauge Creek, a tributary of the East Branch, as a part of independent hydrological research. Efforts will be made to collect and analyze data from both the existing, downstream gauge, and from the new, small gauge.

Project:	Stream flow monitoring
Locations:	1) East Branch, downstream from SDSF, 2) Gauge Creek
Frequency:	annual summary reports
Time of year:	year-round
Methodology:	Collect flow analyses for SDSF records.

8. Precipitation is currently measured near the forest, by a local hydrologist. The station is located on property adjacent to the Forest, on Long Ridge Road. An additional station will be added on Gauge Creek, in conjunction with the stream gauge (see Planned Action 7). SDSF will systematically collect analyses from the stations' monitor.

9. SDSF will continue to encourage the participation of local researchers, and make an effort to extend research opportunities to more community groups, institutions and volunteers. Research on SDSF has been conducted by students and faculty from several schools, including UC Santa Cruz, UC Berkeley and from California Polytechnic University in San Luis Obispo. SDSF plans to encourage the continued participation of these institutions and to involve more volunteers especially for educational efforts.

Preventing Habitat Degradation

SDSF will adhere to the California Forest Practice Regulations, which emphasize the prevention and mitigation of sediment input into watercourses.

1. Late-succession management zones will be established within 300 feet of all Class I streams. Timber will be removed from these areas to promote and maintain late-succession habitat characteristics. These zones will protect fish habitat by maintaining the buffering function of the zones, providing for the addition of large woody debris into the stream, and moderating temperature changes caused by direct exposure to sunlight.

2. Timber harvest operations will include mitigation and enhancement projects that will address and correct pre-existing erosion problems. Additional erosion problems will be avoided by planning timber operations with consideration to erosion, watercourse integrity, and water quality.

3. Adverse impacts of recreation on fish habitat will be addressed by educational efforts. These will include interpretive written material and educational tours. Recreationists will be informed about the SDSF fishery and stream ecosystem, and alerted to the importance of using care around streams. SDSF management will continue to enforce laws prohibiting the poaching of fish on in the area.

4. Sites of critical in-stream instability will be targeted for stabilization efforts. Stabilization projects will only be undertaken if they are considered to be suitable and lasting. Projects may include revegetation or the installation of boulder riprap at the base of unstable hillslopes. Such projects will be undertaken with the advice and cooperation of concerned agencies such as: the Resource Conservation District of Santa Cruz County, Department of Mines and Geology, the Regional Water Quality Control Board, CDF, and other resource specialists. A detailed description of project sites, designs, priorities, schedules and funding will be developed, after initial field investigations are completed.

Project:	Investigate unstable streambanks for possible treatment; write a detailed plan for implementation of projects.
Time:	as needed
Personnel:	2-4 people, including representatives of concerned agencies such as RCD and CDFG.

Methodology:	Get input from concerned agencies to determine where mitigation could be successful. Hike Amaya Creek or the East Branch Above Ashbury Falls, and assess unstable sites

Project:	Plant willow and alder cuttings in unstable streambank along Hihn's Mill Road.
Time:	2-3 days
Personnel:	2 people
Methodology:	Use Resource Conservation District Guidelines, in appendix.

<u>Habitat Improvements and Restoration</u>

Restoration efforts will be undertaken to improve existing habitat conditions, and will focus on those parameters that were found to be lacking in the habitat survey of 1994. A detailed plan, identifying project sites, designs, priorities, schedules and funding will be developed. Where appropriate, projects may be incorporated into timber operations to take advantage of material and equipment operating near restoration sites. CDFG approval will be secured for all projects involving in-stream work.

1. The addition of approximately 1,000 feet of pool length in the second reach of the East Branch would raise the proportion of pools to riffles to a more hospitable level. Structures that create pools by increasing scour would increase pool habitat. Initial field work will be performed to assess the suitability of sites for pool formation within reach 2 of the East Branch. The Department of Fish and Game and the County of Santa Cruz will be consulted as to project design and implementation.

Project:	Survey reach 2 of the East Branch (between Amaya Creek and Fern Gulch); assess possible project sites; write a detailed plan for project implementation.
Personnel:	1-2 CDF, 1+ CDFG, 1+ County official
Time of Year:	Late spring, early summer 1996
Methodology:	Contact Department of Fish and Game restoration specialists in spring, 1996, for help and advice with survey.

2. The adequacy of cover on Amaya Creek and in reach 2 of the East Branch will be investigated. If it is found to be lacking, cover may be improved by the addition of anchored woody debris or boulders to the creek. Improvement projects could take place in conjunction with pool-enhancement projects, mentioned above. CDFG and Santa Cruz County officials will be consulted as to project design and implementation.

3. The alleviation of excessive sedimentation will be addressed as much as possible by hillslope stabilization efforts, discussed above. However, in the event of unusual and

massive sediment input, actions may be taken to remove excessive matter from affected areas.

4. Potential barriers will be located incidentally during annual population surveys. They will be assessed to determine whether they are blocking migration. Assessment will be incorporated into electrofishing efforts; short sampling efforts upstream of a jam should collect juveniles if the barrier is passable at winter flows. Jams will be removed only if they are found to block upstream migration.

Cooperative Watershed Efforts
SDSF staff has been involved in the development of the Soquel Watershed Group. This group brings watershed residents and users together to work towards solving watershed problems, and improving conditions throughout the watershed. SDSF will continue to participate in these efforts, and pursue cooperative relations with other watershed residents and users.

FUNDING

Several possible sources of funding for future research and restoration have been identified. Descriptions and application procedures are described below.

1. The California Forest Improvement Program (CFIP) is administered by CDF to fund projects that exemplify forest stewardship. The enhancement of fish and wildlife habitat is specifically mentioned in the CFIP literature: "CFIP may finance projects designed to improve fish and wildlife habitat, such as removing obstacles to fish migration, planting streamside vegetation, and burning brush to stimulate and improve browse and habitat" (CDF, 1993c) A written project description, including a map of the project area, and a budget for the proposed project should be submitted to CFIP staff in the early spring of each year.

2. The California Department of Fish and Game sponsors certain fisheries-related work under their Fishery Restoration Grants Program. Specifically, the funds are "for implementation of solutions to problems affecting fisheries, rather than for research or experimentation" (CDFG, 1994b). Projects improving historic Coho streams are especially encouraged. An application is received annually from CDFG. Applications are due in the spring for the following fiscal year. Work funded cannot begin before mid-November.

3. The Santa Cruz County Resource Conservation District (RCD) is currently acting as funding center for watershed-related projects and research. Written proposals and budgets for projects should be submitted to the RCD office. These will be reviewed by the Soquel Watershed Group steering committee. No firm deadlines apply.

4. Funding for fisheries research or enhancements may also be sought from corporations, foundations or private sources.

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APPENDIX A : 1994 SDSF Fish Habitat Survey Report

INTRODUCTION

During the summer of 1994, a fish habitat survey was conducted on Soquel Demonstration State Forest (SDSF) property. The survey covered most of the East Branch of Soquel Creek within SDSF, and all of Amaya Creek, a tributary of Soquel Creek which is located on SDSF property. The main objectives of this effort were to describe and assess the condition of fish habitat within SDSF property, and to set precedent for future surveying efforts. Ultimately, the description derived from this survey will be used to guide SDSF planning of management activities that could impact fisheries habitat quality.

Field work for the survey was performed primarily by Twyla Anderson and Jeremy Brown, students at California Polytechnic University, San Luis Obispo, under the guidance of Professor Dr. James Vilkitis. Additional help was provided by SDSF volunteer Bronwen Berlekamp, and staff Angela Petersen, Rich Eliot and Thom Sutfin. Funding for the survey was provided by California Department of Forestry and Fire Protection.

METHODOLOGY

The survey followed protocol set by the California Department of Fish and Game (CDFG) California Salmonid Stream Habitat Restoration Manual (Flosi and Reynolds, 1991). In accordance with this procedure, reaches of stream were defined by distinct channel type, and distinct habitat units were defined within each reach. According to Rosgen's channel classification system (1985), four parameters determine channel type: 1)water slope gradient, 2)channel confinement, 3)width/depth ratio and 4)dominant substrate. About thirty parameters define each habitat unit. These measurements fall into five broad categories: 1) habitat type, 2) physical dimensions, 3) shelter description, 4) substrate description, 5) canopy description and 6) bank description. A brief explanation of the methodology for habitat unit typing follows.

1)Habitat Type
A habitat unit is defined by its type, which is drawn from a list of twenty-five possible types in the California Salmonid Stream Habitat Restoration Manual. Each type is a subcategory of the three general habitat types: riffle, flatwater and pool. Riffles are further categorized as cascade or riffle, according to the gradient of the unit. Pools are further categorized as main channel, scour, or backwater pools, according to the underlying structure that causes pool formation.

2)Physical Dimensions
The mean length, mean width, mean depth and maximum depth are measured for each habitat unit. Extra measurements are taken at each pool habitat unit at the pool tail crest (the downstream end of a pool). Depth and embeddedness of substrate are measured at each pool tail crest.

3)Shelter Description
These parameters describe the shelter, or cover, available for fish within each habitat unit. Visual estimates are made of cover provided by undercut banks, small and large woody debris, root masses, terrestrial and aquatic vegetation, white water, boulders, and bedrock ledges.

4)Substrate Description
The dominant substrate for each habitat unit is recorded as: silt/clay, sand, gravel, small or large cobble, boulder, or bedrock.

5)Bank Composition
The composition of streambanks can determine the susceptibility or resistance of in-stream habitat to the erosive effects of high winter flows. Dominant bank composition is described as: bedrock, boulder, cobble/gravel, bare soil, grass, brush, deciduous trees or coniferous trees. The amount of vegetation on each bank is visually estimated and recorded as a percentage.

6)Canopy Description
Canopy is visually estimated and notated as percent deciduous or coniferous trees.

Stream flows were not taken, due to the lack of equipment. Data was analyzed in part by the software program HABITAT, developed by the California Department of Fish and Game. Tables produced by HABITAT are included as an appendix to this report.

RESULTS

Soquel Creek

The East Branch of Soquel Creek was surveyed from its intersection with the southern boundary of SDSF to approximately 0.5 mile downstream of SDSF's eastern boundary. Funding limitations curtailed the survey before the full length of the creek on SDSF property could be mapped. A total of 29606 feet of the East Branch was surveyed.

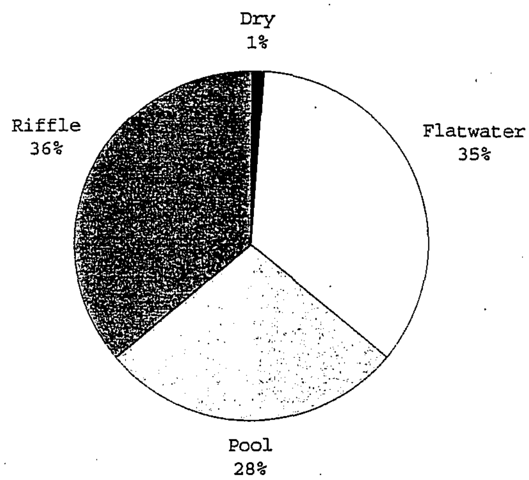
Three channel types were designated on Soquel Creek: B3 (13.2% by length), C1 (37.8% by length), and B1 (49% by length), in order moving upstream. Type B3 is described in the California Salmonid Stream Habitat Restoration Manual as "Moderate gradient; unstable rejuvenating slopes; cobble/gravel channel; source of unlimited sediment supply." Reach 1 (B3) stretched from the southern boundary of SDSF to approximately 775 feet below the confluence with Amaya Creek. Reach 2 (C1) stretched to the area between Fern Gulch and Ashbury Falls (approximately 4370 feet downstream of the Falls, and 1730 feet upstream of Fern Gulch trail). Channel type C1 is described as "Gentle gradient; cobble bed meandering channel with developed flood plain." Type B1, the channel type designated for the remainder of the stream surveyed, is described as "Moderate gradient, stable, small boulder/large cobble channel."

Three hundred and ninety two separate habitat units were recorded. Of the units sampled, 38% were classified as pools, 36% were riffle, 25% were flatwater, and 1% of the units were dry. By length, 36% of the stream surveyed was riffle, 35% was flatwater, 28% was pool, and <1% was dry (Figure 1). The overall pool:riffle ratio was .78:1. The proportional presence of habitat types varied by reach. Notably, pool:riffle ratios were >1:1 in reaches one and three; however, in reach two (C1), the ratio was well below optimum at .47:1. Also noteworthy is that all three dry habitat units occurred in reach three, above Ashbury Falls (Table 1).

Table 1. Habitat Types by Length on the East Branch (by Reach)

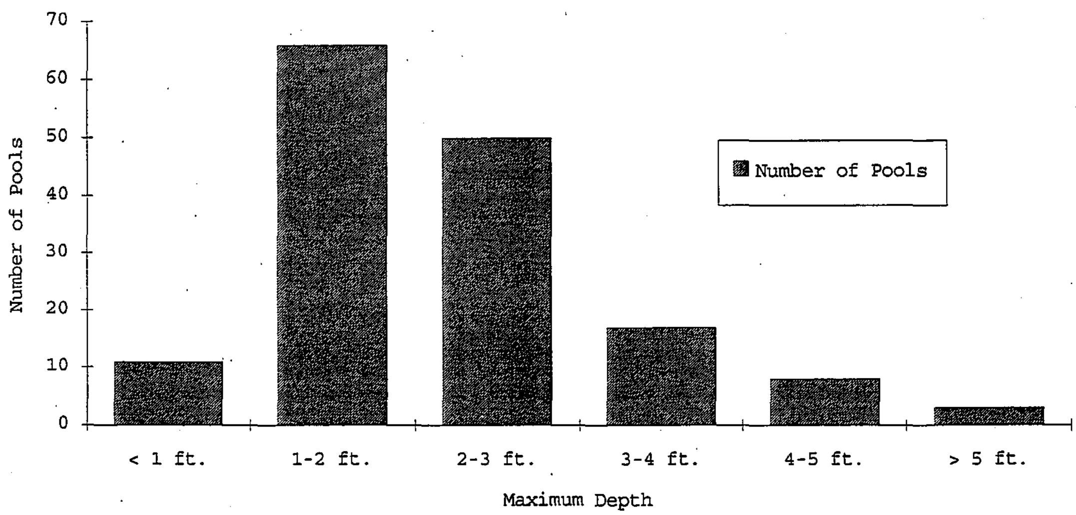
	% riffle	% flatwater	% pool	% dry
East Branch	36	35	28	1
Reach 1 (B3)	33	31	35	0
Reach 2 (C1)	43	36	20	0
Reach 3 (B1)	31	35	32	2

Figure 1. Percentages of Habitat Types by Length on the East Branch



Low-gradient riffle was the most common habitat type on the East Branch overall, representing 23% of all habitat types, and 24% by length of the stream surveyed. 26% by length of the stream was classified as the flatwater habitat step run. Fifty-one percent of pools were main channel pools, 43% were scour pools, and 6% were backwater pools. Pools with a maximum depth of 1-2 ft. were most common, comprising 42% of all pools (Figure 2). The majority of pools were deeper than two feet.

Figure 2. Distribution of Pools by Maximum Depth



Gravel was the most consistently dominant substrate on the East Branch. Silt/Clay substrate, however, was dominant in 15% of pools overall. It was the least represented substrate type in flatwater units, and did not dominate any riffles in SDSF. A higher instance of pools dominated by silt/clay or sand was found in reach one (B3) than in any other reach (Tables 2-4).

Table 2.
Substrate Composition in Riffles on the East Branch (by Reach)

	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Silt/Clay	1 (*)	0	0	1
Sand	1	0	2	0
Gravel	44	35	49	43
Sm. Cobble	21	25	16	23
Lg. Cobble	20	40	22	12
Boulder	11	0	6	18
Bedrock	2	0	2	3

Table 3.
Substrate Composition in Flatwater on the East Branch (by Reach)

	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Silt/Clay	0 (*)	0	0	0
Sand	7	6	8	7
Gravel	59	12	69	69
Sm. Cobble	15	41	8	11
Lg. Cobble	12	24	12	52
Boulder	2	0	0	4
Bedrock	0	0	0	0

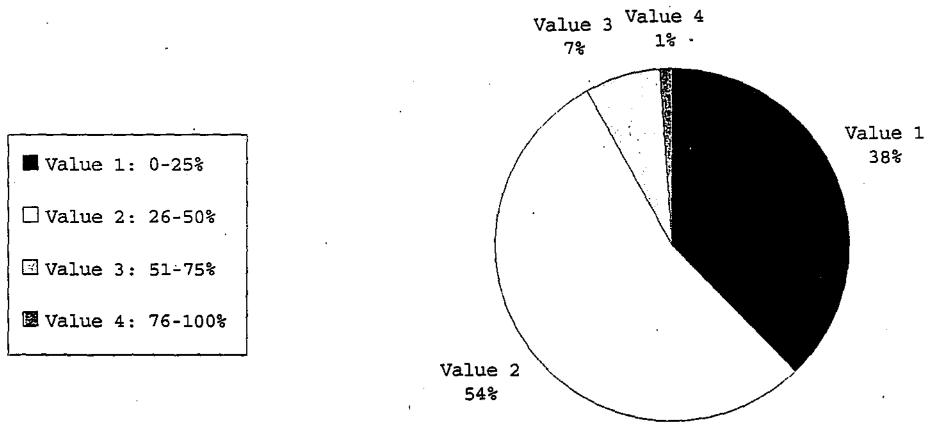
Table 4.
Substrate Composition in Pools on the East Branch (by Reach)

	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Silt/Clay	15 (*)	32	13	12
Sand	28	32	29	27
Gravel	30	21	31	32
Sm. Cobble	7	5	7	8
Lg. Cobble	7	0	11	7
Boulder	8	0	7	9
Bedrock	5	10	2	5

*: represents percentage of units where substrate type is dominant.

Of substrate examined at pool tails, 38% had an embeddedness value of 1 (0-25% embedded), 54% had an embeddedness value of 2 (26-50% embedded), 7% had an embeddedness value of 3 (51-75% embedded), and 1% had an embeddedness value of 4 (76-100%) (Figure 3).

Figure 3. Percent Embeddedness at Pool Tails on the East Branch



Pools had an average of 22% cover, with a range of coverage from 5-75%. Pool types with notably more coverage included plunge pools (average percent cover 41%) and backwater pools formed by instream logs (average percent cover 40%). However, there were so few examples of these pool types, that the significance of these values is difficult to judge. Flatwater habitat units averaged 15% cover, and had a range of 0-50%. Riffles had an average of 17% cover, and ranged in coverage from 0-60%. Mean Percent Cover did not vary drastically between reaches, however, values for Reach 2 (C1) were consistently below average (Table 5).

Table 5. Mean Percent Cover on the East Branch (by Reach)

	riffle	flatwater	pool
East Branch	17	15	22
Reach 1 (B3)	18	18	26
Reach 2 (C1)	16	13	20
Reach 3 (B1)	18	15	22

Cover on the East Branch was consistently dominated by boulders. In pools, bedrock ledges provided the next most cover. In riffles, whitewater was the second most common cover source. In flatwater, other cover types were evenly represented. Cover composition varied somewhat from reach to reach (Tables 6-8).

Table 6. Cover Composition in Pools on the East Branch (by Reach)

	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Undercut Banks	4 (*)	11	10	1
Sm. Woody Debris	4	4	6	4
Lg. Woody Debris	4	6	7	3
Rootwad	7	13	18	2
Terr. Vegetation	3	5	5	2
Aqu. Vegetation	0	0	0	1
Whitewater	6	0	1	11
Boulder	52	14	47	62
Bedrock	20	47	6	14

Table 7. Cover Composition in Riffles on the East Branch (by Reach)

	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Undercut Banks	1 (*)	5	2	0
Sm. Woody Debris	7	5	6	4
Lg. Woody Debris	1	0	0	2
Rootwad	1	1	3	2
Terr. Vegetation	5	10	5	3
Aqu. Vegetation	2	1	2	0
Whitewater	16	9	11	13
Boulder	66	68	69	74
Bedrock	1	1	2	2

Table 8. Cover Composition in Flatwater (by Reach)

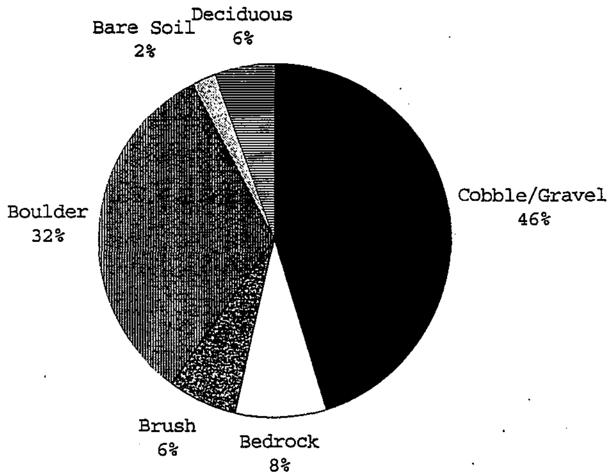
	East Branch	Reach 1 (B3)	Reach 2 (C1)	Reach 3 (B1)
Undercut Banks	4 (*)	13	7	0
Sm. Woody Debris	4	7	6	4
Lg. Woody Debris	2	0	4	2
Rootwad	2	4	1	2
Terr. Vegetation	5	7	6	3
Aqu. Vegetation	1	0	2	0
Whitewater	9	6	4	13
Boulder	70	63	69	74
Bedrock	3	0	1	2

*: mean percent occurrence of cover type.

Coniferous trees provided 75% of canopy over the stream channel. Deciduous trees provided 4% of canopy; the remaining 21% was open.

Banks along the length of stream surveyed were dominated by cobble/gravel, which was the dominant type along 46% of habitat units. Bare soil was the least common bank component, dominating only 2% of habitat units (Figure 4).

Figure 4. Bank Composition on the East Branch



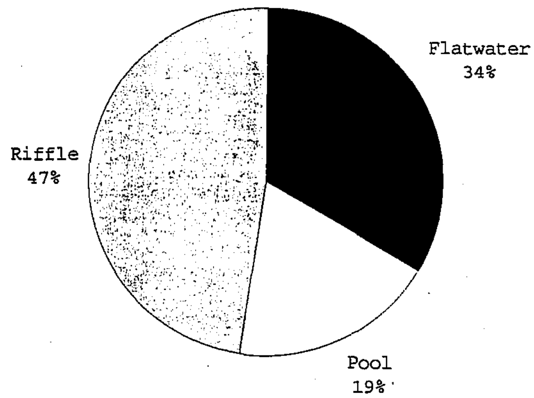
Amaya Creek

Amaya Creek was surveyed from its confluence with the East Branch of Soquel Creek to its intersection with the northern boundary of SDSF. In all, 8152 feet of Amaya Creek were surveyed.

Amaya Creek was designated as channel type B4, which is described in the California Stream Habitat Restoration Manual as "Moderate gradient, relatively fine river terraces, unstable gravel/sand channel."

One hundred and forty one habitat units were recorded. Of the units sampled, 40% were classified as pool, 38% were riffle, and 22% were flatwater. By length, 47% of the stream was riffle, 34% was flatwater, and 19% was pool (Figure 5). The pool to riffle ratio was approximately 0.4:1.

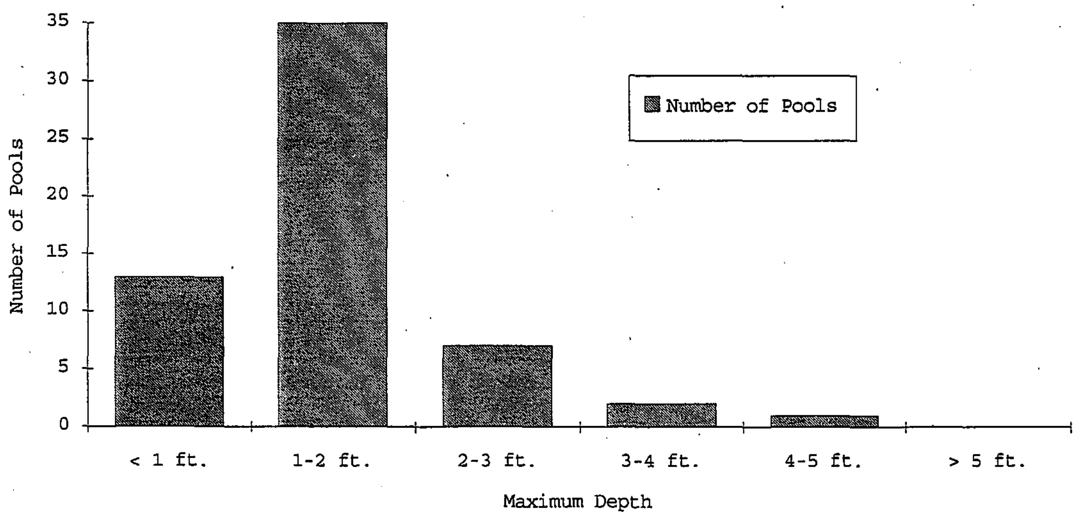
Figure 5. Habitat Types by Percent Occurrence on Amaya Creek



Low gradient riffle was the most common habitat type in Amaya Creek, representing 35% of all units, and 44% of the stream by length. The flatwater type step run covered the next most length of stream, covering 25% of the stream.

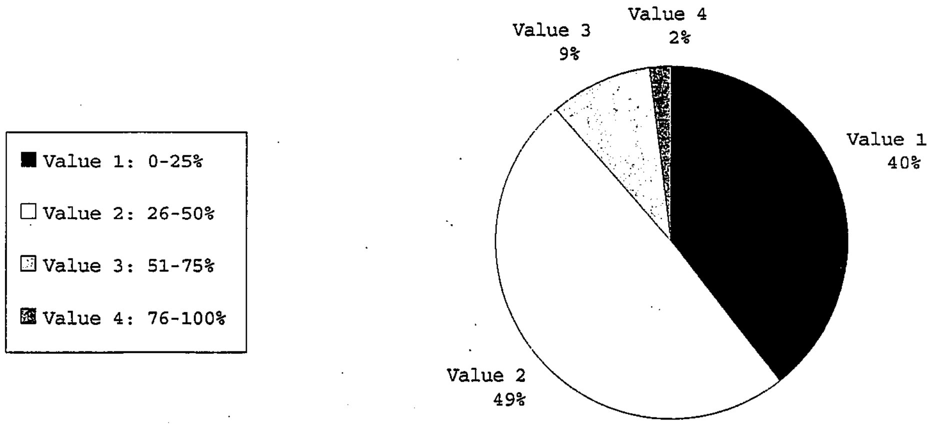
On Amaya Creek, 55% of pools surveyed were scour pools, 43% were main-channel pools, and 2% were backwater pools. Pools with a maximum depth of 1-2 feet were most common, comprising 62.5% of all pools. Pools with maximum depth of less than one foot were the next most common (Figure 6).

Figure 6. Distribution of Pools by Maximum Depth on Amaya Creek



Of the substrate examined at pool tails, 40% had an embeddedness value of 1 (0-25% embedded), 49% had an embeddedness value of 2 (26-50% embedded), 9% had an embeddedness value of 3 (51-75% embedded), and 2% had an embeddedness value of 4 (76-100% embedded) (Figure 7).

Figure 7. Percent Embeddedness at Pool Tails on Amaya Creek



Silt/clay substrate was more predominant in general on Amaya Creek than on the East Branch. Pools were dominated by silt/clay; substrate in riffle and flatwater units was dominated by gravel.

Table 9. Substrate Composition in Amaya Creek (by Habitat Type)

	Riffle	Flatwater	Pool
Silt/Clay	4 (*)	19	42
Sand	13	23	20
Gravel	76	42	2
Sm.Cobble	6	13	2
Lg. Cobble	4	13	2
Boulder	0	0	3
Bedrock	0	0	2

*: percentage of units where substrate is dominant.

Pools had an average of 22% cover, and a range of 5-60% cover. No specific pool type varied significantly from the combined average. Flatwater units had an average of 15% cover, and ranged from 5-50%. Cover in riffles averaged 13%, and had a range of 0-60%. On the average, cascades provided the most cover of all riffle types with

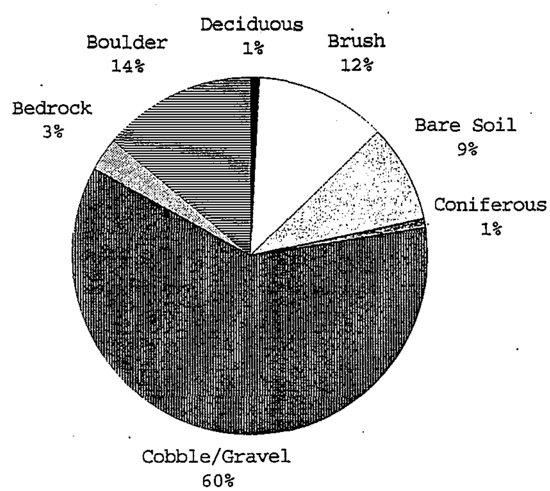
27% cover. Overall, cover types were diverse, with the bulk of cover in flatwater units being provided by terrestrial vegetation (32%), boulders (23%) and small woody debris (19%). Cover in pools was provided largely by boulders (27%) and large woody debris (21%) (Table 10).

Table 10. Cover Composition on Amaya Creek (by Habitat Type)

%	Riffle	Flatwater	Pool
Undercut Banks	2	6	10
Sm. Woody Debris	14	19	12
Lg. Woody Debris	8	13	20
Root Mass	0	1	5
Terr. Veg.	37	32	16
Aqu. Veg.	0	3	0
Whitewater	5	4	2
Boulder	35	23	27
Bedrock	0	0	7

Cobble/gravel dominated the banks along Amaya Creek, covering 60% of the banks. Boulders and brush were also common dominant types. Bare soil dominated 9% of all habitat types (Figure 8).

Figure 8. Bank Composition on Amaya Creek



Coniferous trees provided 45% of the canopy on Amaya Creek; deciduous trees comprised 2% of the canopy. The remaining 53% was open.

DISCUSSION

Objectives and Approach

It is the chief intention of SDSF management to maintain and improve habitat for existing populations. Therefore, creek habitat in SDSF has been analyzed specifically for its suitability for steelhead/rainbow trout because a successful population currently exists. In recent years, Coho salmon populations have dwindled on all creeks south of San Francisco Bay, including Soquel Creek (Hope, 1993). Surveys and incidental sightings indicate that Coho are very rarely found on Soquel Creek, so rarely, that there is considered to be no stable population on Soquel Creek (Hope, 1993). The habitat requirements of Coho are very similar to those for steelhead; the main distinction is that juvenile Coho tend to live in well-covered pools, while juvenile steelhead are most often found in riffles (Milne, 1948 in Barnhart, 1986). Because their requirements are so similar, most of the qualities that make habitat hospitable for steelhead also apply to Coho habitat and vice versa. Thus, if Coho or any other species benefit from SDSF's management activities, their success will be noted, and their specific habitat requirements accounted for. At this time, however, habitat quality will be assessed in terms of its suitability for steelhead.

Steelhead Biology and Habitat Requirements

Habitat requirements for steelhead vary with life-stage and season. In general, a 1:1 pool to riffle ratio is most hospitable to steelhead (Raleigh and Duff 1980 in Raleigh et al. 1984). Adult migration occurs during winter months, when peak flows facilitate upstream movement. A minimum depth of 7 inches is necessary for upstream migration (Thompson, 1972 in Barnhart, 1986), and optimum water temperatures for migration range from 46-52 F (Barnhart, 1986). In dry periods, when the creek is especially low, timing of peak winter flows can determine the successful migration of adult fish (Harvey and Stanley, 1982). Cover greater than 25% is optimum for adult fish (Raleigh et al. 1984). Spawning begins once migration is accomplished, and requires a different set of specific conditions. Optimum temperatures for spawning range from 39-52 F (McEwan and Jackson, 1994). Spawning and egg incubation is most successful in gravelly substrate, where interstitial water movement is sufficient to oxygenate the eggs, but water velocity is not great enough to disturb them (Behnke, 1992). These conditions are most often present at pool-tails (CDFG, 1994). Excessive sediment in these areas can clog interstitial spaces, reducing oxygen flow, abrading eggs, and causing gill damage in adult fish (Barnhart, 1986). Embeddedness of substrate at pool-tails is an indicator of sedimentation, and therefore a good indicator of spawning habitat quality. Upon hatching, juvenile fish gather in shallow flatwater often at stream edges (Barnhart, 1986). During this time, they especially need protective cover (Behnke, 1992; Harvey and Stanley, 1982), and thrive in temperatures ranging from 45-60 F (McEwan and Jackson, 1994). As they mature, they gravitate towards riffle areas (Behnke, 1992; Barnhart, 1986), where they thrive in cover levels of 15% or greater (Raleigh et al., 1984). Once they have reached maturity, they may migrate downstream to the ocean, or they may stay for up to three years in freshwater before migrating. Resident trout never migrate to the ocean. Overwintering habitat is especially important for those fish who do not migrate after their first year of life. Deep pools with plenty of cover provide optimum overwintering habitat (Benhke, 1993).

Discussion of Results

Optimum conditions for steelhead were compared to actual field conditions as they are described by the habitat inventory.

All habitat types were well represented on Soquel Creek. The pool to riffle ratio, however, falls below the optimum 1:1, at .78:1. The shortage of pools was concentrated in reach two (C1), where the pool to riffle ratio was .46:1. Overall, pool depths are sufficient for adult and overwintering habitat. Mean depths for Soquel Creek were greater than those required for adult migration, even at low summer flow. Migration through SDSF on the East Branch was free of obstacles from the southern border to Ashbury Falls.

On Amaya Creek, riffle habitat dominates, and pools tend to be shallow (<2 ft.). The pool:riffle ratio is just .4:1, well below the optimum value. The passability of Amaya Creek is unclear; several potential barriers, such as fallen trees, may be impeding fish passage.

The predominantly gravel substrate on the East Branch provides good conditions for spawning and for juvenile fish. However, the high instance of silt/clay substrate in pools detracts from the otherwise good substrate conditions. Siltation is especially marked in Reach One (B3) pools, which receive sediment from both Amaya Creek and the East Branch. On Amaya Creek, where silt/clay substrate is second only to small cobble in dominance, spawning and juvenile habitat is less than optimum. Despite these signs of sedimentation on Amaya Creek, substrate at pool tail-outs is not excessively embedded. Embeddedness values on the East Branch are similarly low, indicating that spawning areas are not chronically sedimented.

Cover in both creeks is diverse, but it may not be adequately abundant. Pool habitats in both creeks have an average of 22% cover. Flatwater habitats have an average of 15% cover in both creeks. Cover in riffle habitats averages 17% on the East Branch and 13% on Amaya Creek. On the East Branch, the lack of cover is fairly evenly distributed over all reaches; reach two (C1) is the only reach that has below-average cover in all habitat types.

The two creeks inventoried in this survey differ significantly in their fundamental stabilities. The Amaya Creek drainage is considered to be quite geologically unstable along its entire course, while Soquel Creek stability varies along its length. According to both the Pfankuch stream channel stability study of 1992, and the stability survey performed according to CDF protocol, Amaya Creek has "poor" stability, while Soquel Creek has "fair" stability (Cafferata and Poole, 1993). Their relative stabilities may affect the quality of fish habitat in each creek. The more unstable Amaya Creek shows some signs of having chronic sedimentary input: a high instance of bare soil as a bank component, a dominance of silt/clay and sand substrate, and a shortage of pools.

CONCLUSIONS

The results of this survey indicate that fish habitat on the East Branch is fair overall, but lacking in two particular parameters: poolspace and cover. The lack of pools is concentrated in reach two (C1), which stretches from below Amaya Creek to above Fern Gulch. Cover is lacking throughout, and is slightly less adequate in reach two (C1) as well. The status of cover and the adequacy of pools should be investigated and evaluated by fisheries specialists, and options for improvement should be assessed. The status of cover and poolspace on Amaya Creek are further from optimum levels, and should also be investigated.

Habitat in both creeks seems to suffer from the inherent instability of the watershed. On the East Branch, sedimentation is limited to pools; levels are concentrated below the confluence with Amaya Creek. On Amaya Creek, silt/clay comprises a significant portion of substrate throughout the stream, and pools are generally shallow. It is unclear, however, how greatly pool depth is influenced by sedimentation; shallowness might also be attributed to underlying structure or to recent low flows. Relatively unembedded substrate at pool tails suggests that sediment has not pervaded the habitat. Because the influence of sedimentation on Amaya Creek habitat is unclear, levels of sedimentation should be assessed through research and monitoring, and options for improvement should be evaluated.

Full-scale habitat surveys such as this one should be conducted every 10 years, depending on funding, storm patterns, potential projects and forest management activities that could impact fish habitat. Future surveys should follow the methodology used here as closely as possible, incorporating updates and modifications of protocol. In this way, data comparisons will be possible.

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East Branch Soquel Creek

Drainage: Soquel Creek

Table 1 - SUMMARY OF RIFFLE, FLATWATER, AND POOL HABITAT TYPES

Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	MEAN LENGTH (ft.)	TOTAL LENGTH (ft.)	PERCENT TOTAL LENGTH	MEAN WIDTH (ft.)	MEAN DEPTH (ft.)	MEAN AREA (sq.ft.)	TOTAL AREA (sq.ft.)	MEAN VOLUME (cu.ft.)	TOTAL VOLUME (cu.ft)	MEAN RESIDUAL POOL VOL (cu.ft.)	MEAN SHELTER RATING
143	RIFFLE	36	74	10633	36	10.4	0.5	700	100112	358	51178	0	29
97	FLATWATER	25	107	10402	35	10.6	0.7	1019	98845	748	72534	0	27
149	POOL	38	55	8220	28	12.2	1.3	626	93267	892	132871	600	44
3	DRY	1	117	351	1	0.0	0.0	0	0	0	0	0	0

TOTAL UNITS	TOTAL LENGTH (ft.)	TOTAL AREA (sq. ft.)	TOTAL VOL. (cu. ft.)
392	29606	292224	256583

East Branch Soquel Creek

Drainage: Soquel Creek

Table 2 - SUMMARY OF HABITAT TYPES AND MEASURED PARAMETERS

Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED #	HABITAT TYPE	HABITAT OCCURRENCE %	MEAN LENGTH ft.	TOTAL LENGTH ft.	TOTAL LENGTH %	MEAN WIDTH ft.	MEAN DEPTH ft.	MAXIMUM DEPTH ft.	MEAN AREA sq.ft.	TOTAL AREA sq.ft.	MEAN VOLUME cu.ft.	TOTAL VOLUME cu.ft.	MEAN RESIDUAL POOL VOL cu.ft.	MEAN SHELTER RATING	MEAN RT. BANK VEGETATED %	MEAN LT. BANK VEGETATED %	MEAN CANOPY %
91	LGR	23	79	7195	24	11	0.5	1.6	778	70793	374	34043	0	25	41	29	77
40	HGR	10	79	3146	11	10	0.6	2.0	681	27250	408	16314	0	38	20	26	84
11	CAS	3	26	284	1	7	0.4	1.6	188	2065	75	820	0	37	7	7	87
1	BRS	0	9	9	0	0	0.3	0.3	3	3	1	1	0	0	0	0	50
3	GLD	1	42	125	0	16	0.4	1.3	682	2046	378	1133	0	12	37	57	87
49	RUN	13	54	2640	9	10	0.7	1.6	524	25665	341	16728	0	20	33	29	74
45	SRN	11	170	7638	26	11	0.7	2.3	1581	71134	1215	54674	0	35	35	35	81
44	MCP	11	53	2319	8	12	1.1	3.3	646	28435	790	34756	450	33	37	33	85
32	STP	8	85	2711	9	11	1.0	3.3	761	24359	750	23993	476	45	18	15	80
15	LSR	4	43	646	2	12	1.3	14.8	497	7455	690	10348	479	62	21	45	94
29	LSBk	7	59	1702	6	12	1.8	6.2	765	22171	1595	46242	1239	46	36	25	78
16	LSBo	4	32	514	2	12	1.5	4.3	353	5645	589	9426	388	36	18	12	68
4	PLP	1	20	78	0	14	2.1	5.6	301	1203	869	3476	623	83	3	1	76
1	BPR	0	18	18	0	10	0.7	1.6	172	172	114	114	0	50	40	10	5
3	BPL	1	28	83	0	21	0.9	2.3	580	1739	726	2179	416	107	50	27	70
5	DPL	1	30	149	1	14	1.3	3.9	418	2089	468	2338	252	48	20	6	79
3	DRY	1	117	351	1	0	0.0	0.0	0	0	0	0	0	0	0	0	0

TOTAL UNITS	LENGTH (ft.)	AREA (sq.ft)	TOTAL VOL. (cu.ft)
392	29606	292224	256583

East Branch Soquel Creek

Drainage: Soquel Creek

Table 3 - SUMMARY OF POOL TYPES

Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	MEAN LENGTH (ft.)	TOTAL LENGTH (ft.)	PERCENT TOTAL LENGTH	MEAN WIDTH (ft.)	MEAN DEPTH (ft.)	MEAN AREA (sq.ft.)	TOTAL AREA (sq.ft.)	MEAN VOLUME (cu.ft.)	TOTAL VOLUME (cu.ft)	MEAN RESIDUAL POOL VOL. (cu.ft.)	MEAN SHELTER RATING
76	MAIN	50	66	5030	59	11.7	1.1	695	52794	773	58749	461	38
64	SCOUR	42	46	2940	34	12.2	1.6	570	36474	1086	69491	810	49
9	BACKWATER	6	28	251	3	16.0	1.1	444	4000	514	4630	279	68
3	DRY	2	117	351	4	0.0	0.0	0	0	0	0	0	0

TOTAL MEASURED	TOTAL LENGTH (ft.)	TOTAL AREA (sq.ft.)	TOTAL VOL. (cu.ft.)
152	8571	93267	132871

East Branch Soquel Creek

Drainage: Soquel Creek

Table 4 - SUMMARY OF MAXIMUM POOL DEPTHS BY POOL HABITAT TYPES

Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	<1 FOOT MAXIMUM DEPTH	<1 FOOT PERCENT OCCURRENCE	1-<2 FT. MAXIMUM DEPTH	1-<2 FOOT PERCENT OCCURRENCE	2-<3 FT. MAXIMUM DEPTH	2-<3 FOOT PERCENT OCCURRENCE	3-<4 FT. MAXIMUM DEPTH	3-<4 FOOT PERCENT OCCURRENCE	>=4 FEET MAXIMUM DEPTH	>=4 FEET PERCENT OCCURRENCE
44	MCP	29	2	5	26	59	14	32	2	5	0	0
32	STP	21	1	3	18	56	12	38	1	3	0	0
15	LSR	10	1	7	7	47	3	20	2	13	2	13
29	LSBk	19	0	0	3	10	11	38	8	28	7	24
16	LSBo	11	0	0	6	38	7	44	2	13	1	6
4	PLP	3	0	0	2	50	0	0	1	25	1	25
1	BPR	1	0	0	1	100	0	0	0	0	0	0
3	BPL	2	0	0	2	67	1	33	0	0	0	0
5	DPL	3	1	20	1	20	2	40	1	20	0	0
3	DRY	2	3	100	0	0	0	0	0	0	0	0

TOTAL
UNITS
152

East Branch Soquel Creek Drainage: Soquel Creek

Table 5 - SUMMARY OF MEAN PERCENT COVER BY HABITAT TYPE Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED	HABITAT TYPE	MEAN % UNDERCUT BANKS	MEAN % SWD	MEAN % LWD	MEAN % ROOT MASS	MEAN % TERR. VEGETATION	MEAN % AQUATIC VEGETATION	MEAN % WHITE WATER	MEAN % BOULDERS	MEAN % BEDROCK LEDGES
91	LGR	2	7	1	1	6	2	11	69	1
40	HGR	1	7	2	0	3	1	21	64	2
11	CAS	0	4	1	0	0	0	39	55	0
1	BRS	0	0	0	0	0	0	0	0	0
3	GLD	30	3	0	2	23	0	0	15	27
49	RUN	3	4	3	2	4	1	3	76	3
45	SRN	3	5	1	2	4	0	15	68	2
44	MCP	8	4	2	5	7	1	2	64	5
32	STP	0	4	4	1	1	0	20	63	7
15	LSR	10	5	8	40	3	0	1	34	0
29	LSBk	3	2	6	2	3	0	2	25	83
16	LSBo	0	3	3	0	2	3	4	82	3
4	PLP	0	3	4	0	0	0	24	35	36
1	BPR	0	10	0	85	0	0	0	5	0
3	BPL	18	2	8	38	2	0	0	7	25
5	DPL	6	29	7	5	0	1	3	49	0
3	DRY	0	0	0	0	0	0	0	0	0

East Branch Soquel Creek

Drainage: Soquel Creek

Table 6 - SUMMARY OF DOMINANT SUBSTRATES BY HABITAT TYPE

Survey Dates: 06/13/11 - 07/22/94

Confluence:

UNITS MEASURED	HABITAT TYPE	# UNITS SILT/CLAY DOMINANT	% TOTAL SILT/CLAY DOMINANT	# UNITS SAND DOMINANT	% TOTAL SAND DOMINANT	# UNITS GRAVEL DOMINANT	% TOTAL GRAVEL DOMINANT	# UNITS SM COBBLE DOMINANT	% TOTAL SM COBBLE DOMINANT	# UNITS LG COBBLE DOMINANT	% TOTAL LG COBBLE DOMINANT	# UNITS BOULDER DOMINANT	% TOTAL BOULDER DOMINANT	# UNITS BEDROCK DOMINANT	% TOTAL BEDROCK DOMINANT
91	LGR	1	1	1	1	46	51	19	21	21	23	2	2	1	1
40	HGR	0	0	0	0	14	35	11	28	7	18	7	18	1	3
11	CAS	0	0	0	0	3	27	0	0	1	9	7	64	0	0
1	BRS	0	0	0	0	0	0	0	0	0	0	0	0	1	100
3	GLD	0	0	0	0	3	100	0	0	0	0	0	0	0	0
49	RUN	0	0	4	8	29	59	9	18	5	10	1	2	0	0
45	SRN	0	0	3	7	28	62	6	13	7	16	1	2	0	0
44	MCP	5	11	12	27	13	30	5	11	4	9	3	7	2	5
32	STP	3	9	4	13	13	41	4	13	3	9	3	9	2	6
15	LSR	0	0	7	47	4	27	1	7	2	13	1	7	0	0
29	LSBk	9	31	9	31	7	24	0	0	1	3	0	0	3	10
16	LSBo	0	0	9	56	4	25	0	0	1	6	2	13	0	0
4	PLP	0	0	1	25	2	50	0	0	0	0	1	25	0	0
1	BPR	1	100	0	0	0	0	0	0	0	0	0	0	0	0
3	BPL	2	67	0	0	0	0	1	33	0	0	0	0	0	0
5	DPL	3	60	0	0	1	20	0	0	0	0	1	20	0	0
3	DRY	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Amaya Creek

Drainage: East Branch Soquel Creek

Table 1 - SUMMARY OF RIFFLE, FLATWATER, AND POOL HABITAT TYPES

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	MEAN LENGTH (ft.)	TOTAL LENGTH (ft.)	PERCENT TOTAL LENGTH	MEAN WIDTH (ft.)	MEAN DEPTH (ft.)	MEAN AREA (sq.ft.)	TOTAL AREA (sq.ft.)	MEAN VOLUME (cu.ft.)	TOTAL VOLUME (cu.ft)	MEAN RESIDUAL POOL VOL (cu.ft.)	MEAN SHELTER RATING
54	RIFFLE	38	71	3852	47	6.3	0.4	354	19137	128	6912	1	27
31	FLATWATER	22	89	2750	34	6.1	0.4	487	15106	186	5773	0	38
56	POOL	40	28	1550	19	8.0	0.9	198	11070	170	9495	95	46

TOTAL UNITS	TOTAL LENGTH (ft.)	TOTAL AREA (sq. ft.)	TOTAL VOL. (cu. ft.)
141	8152	45312	22179

Amaya Creek

Drainage: East Branch Soquel Creek

Table 2 - SUMMARY OF HABITAT TYPES AND MEASURED PARAMETERS

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED #	HABITAT TYPE	HABITAT OCCURRENCE %	MEAN LENGTH ft.	TOTAL LENGTH ft.	TOTAL LENGTH %	MEAN WIDTH ft.	MEAN DEPTH ft.	MAXIMUM DEPTH ft.	MEAN AREA sq.ft.	TOTAL AREA sq.ft.	MEAN VOLUME cu.ft.	TOTAL VOLUME cu.ft.	MEAN RESIDUAL POOL VOL cu.ft.	MEAN SHELTER RATING	MEAN RT. BANK VEGETATED %	MEAN LT. BANK VEGETATED %	MEAN CANOPY %
49	LGR	35	73	3565	44	6	0.4	1.6	367	17964	133	6525	1	26	63	58	75
5	HGR	4	58	288	4	7	0.3	1.3	234	1172	77	387	0	36	161	31	69
14	RUN	10	50	707	9	6	0.4	1.0	297	4154	111	1548	0	21	53	51	77
17	SRN	12	120	2043	25	6	0.4	1.3	644	10952	249	4225	0	52	74	71	78
21	MCP	15	27	567	7	8	0.8	3.0	211	4429	172	3605	98	46	43	49	68
3	STP	2	86	258	3	4	0.4	1.6	369	1108	243	730	122	30	13	15	98
6	LSL	4	23	135	2	8	0.8	2.6	175	1051	144	862	46	64	38	48	73
5	LSR	4	17	87	1	7	0.7	1.6	113	563	77	386	40	64	30	30	70
5	LSBk	4	28	142	2	8	0.8	2.3	196	980	157	784	76	44	54	84	91
9	LSBo	6	26	236	3	8	0.9	3.3	193	1741	173	1559	99	34	44	47	79
6	PLP	4	16	98	1	11	1.3	4.9	178	1071	241	1443	182	45	30	38	91
1	BPB	1	27	27	0	5	1.0	2.0	127	127	125	125	83	10	25	5	100

TOTAL UNITS	LENGTH (ft.)	AREA (sq.ft)	TOTAL VOL. (cu.ft)
141	8152	45312	22179

Amaya Creek

Drainage: East Branch Soquel Creek

Table 3 - SUMMARY OF POOL TYPES

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	MEAN LENGTH (ft.)	TOTAL LENGTH (ft.)	PERCENT TOTAL LENGTH	MEAN WIDTH (ft.)	MEAN DEPTH (ft.)	MEAN AREA (sq.ft.)	TOTAL AREA (sq.ft.)	MEAN VOLUME (cu.ft.)	TOTAL VOLUME (cu.ft)	MEAN RESIDUAL POOL VOL. (cu.ft.)	MEAN SHELTER RATING
24	MAIN	43	34	825	53	7.5	0.8	231	5537	181	4335	101	44
31	SCOUR	55	23	698	45	8.4	0.9	174	5406	162	5035	91	48
1	BACKWATER	2	27	27	2	4.9	1.0	127	127	125	125	83	10

TOTAL MEASURED	TOTAL LENGTH (ft.)	TOTAL AREA (sq.ft.)	TOTAL VOL. (cu.ft.)
56	1550	11070	9495

Amaya Creek

Drainage: East Branch Soquel Creek

Table 4 - SUMMARY OF MAXIMUM POOL DEPTHS BY POOL HABITAT TYPES

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED	HABITAT TYPE	HABITAT PERCENT OCCURRENCE	<1 FOOT MAXIMUM DEPTH	<1 FOOT PERCENT OCCURRENCE	1-<2 FT. MAXIMUM DEPTH	1-<2 FOOT PERCENT OCCURRENCE	2-<3 FT. MAXIMUM DEPTH	2-<3 FOOT PERCENT OCCURRENCE	3-<4 FT. MAXIMUM DEPTH	3-<4 FOOT PERCENT OCCURRENCE	>=4 FEET MAXIMUM DEPTH	>=4 FEET PERCENT OCCURRENCE
21	MCP	38	4	19	15	71	2	10	0	0	0	0
3	STP	5	1	33	2	67	0	0	0	0	0	0
6	LSL	11	1	17	3	50	2	33	0	0	0	0
5	LSR	9	0	0	5	100	0	0	0	0	0	0
5	LSBk	9	0	0	4	80	1	20	0	0	0	0
9	LSBo	16	3	33	3	33	1	11	2	22	0	0
6	PLP	11	2	33	2	33	1	17	0	0	1	17
1	BPB	2	0	0	1	100	0	0	0	0	0	0

TOTAL UNITS
56

Amaya Creek

Drainage: East Branch Soquel Creek

Table 5 - SUMMARY OF MEAN PERCENT COVER BY HABITAT TYPE

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED	HABITAT TYPE	MEAN % UNDERCUT BANKS	MEAN % SWD	MEAN % LWD	MEAN % ROOT MASS	MEAN % TERR. VEGETATION	MEAN % AQUATIC VEGETATION	MEAN % WHITE WATER	MEAN % BOULDERS	MEAN % BEDROCK LEDGES
49	LGR	2	13	7	0	41	0	4	34	0
5	HGR	8	18	14	3	2	0	12	43	0
14	RUN	6	17	18	0	39	6	0	14	0
17	SRN	5	21	9	2	26	0	6	30	1
21	MCP	12	13	22	1	20	0	1	31	0
3	STP	0	18	5	0	18	0	7	18	0
6	LSL	5	13	50	3	7	0	3	13	8
5	LSR	10	21	20	30	2	0	0	17	0
5	LSBk	8	10	0	2	29	0	1	17	33
9	LSBo	14	8	8	2	22	0	1	42	4
6	PLP	7	7	31	11	5	1	3	31	6
1	BPB	0	0	0	0	0	0	5	5	90

Amaya Creek

Drainage: East Branch Soquel Creek

Table 6 - SUMMARY OF DOMINANT SUBSTRATES BY HABITAT TYPE

Survey Dates: 07/01/94, 07/14/94

Confluence:

UNITS MEASURED	HABITAT TYPE	# UNITS SILT/CLAY DOMINANT	% TOTAL SILT/CLAY DOMINANT	# UNITS SAND DOMINANT	% TOTAL SAND DOMINANT	# UNITS GRAVEL DOMINANT	% TOTAL GRAVEL DOMINANT	# UNITS SM COBBLE DOMINANT	% TOTAL SM COBBLE DOMINANT	# UNITS LG COBBLE DOMINANT	% TOTAL LG COBBLE DOMINANT	# UNITS BOULDER DOMINANT	% TOTAL BOULDER DOMINANT	# UNITS BEDROCK DOMINANT	% TOTAL BEDROCK DOMINANT
49	LGR	0	0	2	4	5	10	38	78	3	6	1	2	0	0
5	HGR	0	0	0	0	2	40	2	40	0	0	1	20	0	0
14	RUN	1	7	3	21	6	43	3	21	1	7	0	0	0	0
17	SRN	0	0	3	18	1	6	10	59	3	18	0	0	0	0
21	MCP	6	29	10	48	2	10	1	5	1	5	0	0	0	0
3	STP	0	0	1	33	2	67	0	0	0	0	0	0	0	0
6	LSL	3	50	2	33	1	17	0	0	0	0	0	0	0	0
5	LSR	3	60	2	40	0	0	0	0	0	0	0	0	0	0
5	LSBk	2	40	1	20	1	20	0	0	0	0	0	0	1	20
9	LSBo	2	22	4	44	2	22	0	0	0	0	1	11	0	0
6	PLP	2	33	3	50	1	17	0	0	0	0	0	0	0	0
1	BPB	0	0	0	0	1	100	0	0	0	0	0	0	0	0

SOQUEL DEMONSTRATION STATE FOREST

1994 FISH POPULATION SURVEY REPORT

CALIFORNIA DEPARTMENT OF FORESTRY
AND FIRE PROTECTION

INTRODUCTION

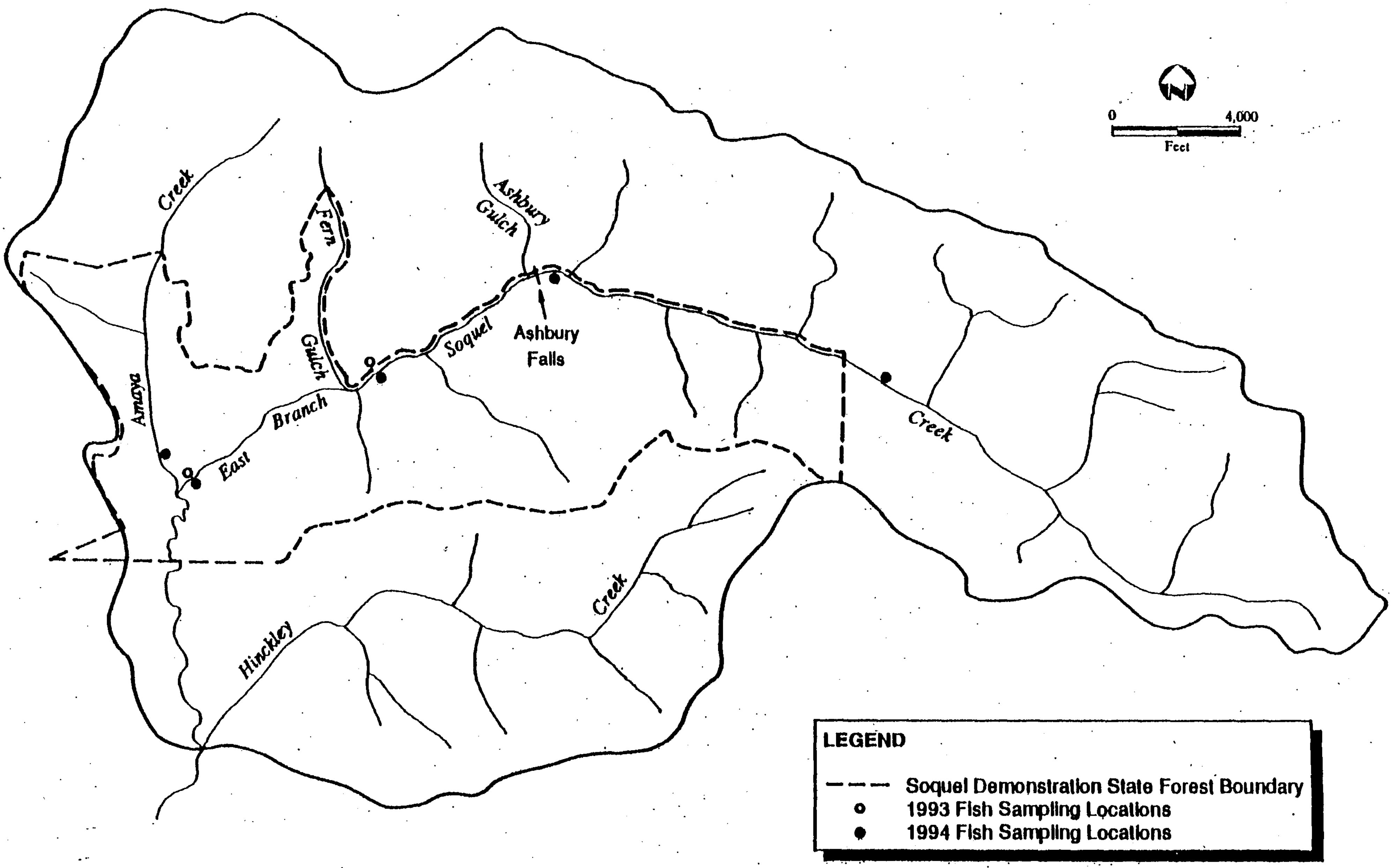
During the month of October, a survey of fish populations was conducted in the Soquel Demonstration State Forest (SDSF), on the East Branch of Soquel Creek and on Amaya Creek, a tributary whose confluence is located in SDSF. Five sites were electrofished; four sites were located on the East Branch of Soquel Creek, one was located on Amaya Creek. Of the four sites on Soquel Creek, three were located in SDSF and one was located upstream from the forest property (see map).

The objective of the survey was twofold. The immediate goal was to identify fish species and distribution in the waterways that pass through SDSF. The long-term goal of the survey was to set precedence for future annual surveys. To best achieve these goals with the time and resources available, both quantitative and qualitative electrofishing surveys were done.

Jennifer Nelson (CDFG), Patricia Anderson (CDFG), Chuck Hoovestol (CDFG), Brad Valentine (CDF Fisheries), Thom Sutfin (SDSF), Rich Eliot (SDSF), Angela Petersen (SDSF) and Bronwen Berlekamp (SDSF) all participated in the surveying efforts at various times.

METHODOLOGY

Quantitative electrofishing surveys were completed at sampling sites 1, 2 and 3 (Amaya Creek, Long-Ridge Road Crossing and Spanish Ranch Trail Crossing, respectively). Each station was 100 yards long, with each end blocked off by seine nets to



Jones & Stokes Associates, Inc.

Approximate Fish Sampling Locations on Amaya Creek and the East Branch

prevent immigration and emmigration during sampling. All stations were fished to depletion. Total lengths (TL) and weights were recorded for each pass, and the fish were returned to the creek, outside of the blocked-off stretch. Air and water temperatures were taken except when a thermometer was unavailable. Flow was not measured, because a flow gauge was not available. For consistency, efforts at each sampling site were completed in one day, and electrofishing was done by only one person each day.

Qualitative sampling was done on the East Branch above Ashbury Falls. At sampling site 4, located in SDSF, efforts at quantitative sampling were curtailed by battery failure. Data was recorded for qualitative purposes. Several sites upstream from SDSF boundaries were sampled on the East Branch. In these efforts, time, rather than length, was limiting; each site was fished for ten minutes.

RESULTS

Population estimates for sites 1, 2, and 3 were derived using the software package MICROFISH, developed by Van Deventer and Platts in 1989. Station 1 (Amaya Creek) had a population estimate of 13, station 2 (Long Ridge Road Crossing) had a population estimate of 87, and station 3 (Spanish Ranch Trail Crossing) had a population estimate of 197 fish.

Quantitative

At Sampling Site 1 (Amaya Creek), one species of fish, steelhead, was captured. Three passes yielded 13 fish, ranging in length from 60-195 mm TL. Newts were also observed in abundance, but were not captured or recorded. The habitat encompassed by the station was mostly flatwater habitat (approx. 46% step run, 23% run), with some low-gradient riffle (approx. 27% low-gradient riffle), and a few pools (approx. 4%) where most of the fish were caught. Habitat percentage estimates were derived from SDSF habitat survey of 1994. Habitat composition estimates were particularly rough for this station, as distinctive landmarks were not available to accurately correlate habitat survey data with the station location. A short, qualitative sample was taken from a pool just upstream from the station. Twenty-one fish were recovered in under 5 minutes.

At Sampling Site 2 (Long Ridge Road Crossing), two species of fish, steelhead and sculpin, were captured. A total of 86 fish were caught, ranging in size from 56-197 mm TL. Newts, immature lamprey, and worms were observed, but not captured. The habitat in the station was mostly low-gradient riffle (approx. 64%), with some run habitat (approx. 21%) with some long and shallow pools (approx. 15%). Habitat percentage estimates were derived from the SDSF habitat survey of 1994.

At Sampling Site 3 (Spanish Ranch Trail Crossing), one species of fish, steelhead, was captured. The 182 fish caught ranged in length from 51-182 mm TL. One Pacific Giant Salamander was also captured. Of special note was a mature lamprey, which was approximately 18 inches in length. The majority of the habitat was low-gradient riffle (approx. 90%). The remainder was pool habitat (approx. 10%). Habitat percentage estimates were derived from SDSF habitat survey of 1994.

Qualitative

Sampling Sites 4 and 5 (above Ashbury Falls and above SDSF, respectively) produced data that provides qualitative information about the populations in these areas. Both sites are located above a significant geological obstacle, Ashbury Falls, which was formed where the San Andreas fault crosses the channel. It is unknown whether the falls are a blockage to upstream migration. Thus, it is also unknown whether the fish above the falls are migratory or resident.

Sampling Site 4 was intended to be fished quantitatively, but battery failure during the second pass cut the sampling short. Like the three quantitative sampling sites, site 4 was 100 yards long and blocked at both ends with seine nets. 127 fish were captured that were similar in appearance, and ranged in length from 54 to 164 mm TL. Habitat type correlation was not available for this site.

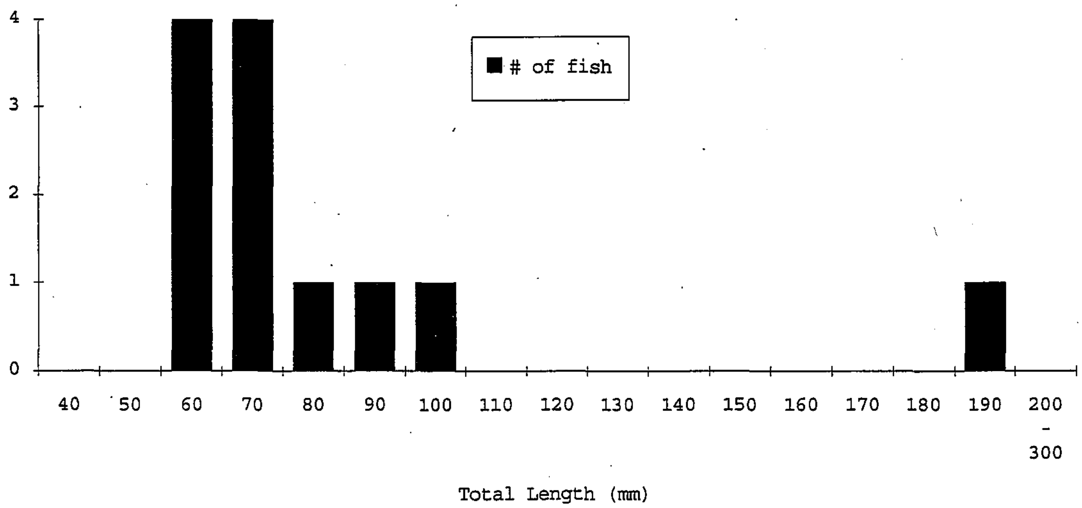
Sampling Site 5 comprised five separate sampling efforts, limited by time. Three of the five timed samplings were located upstream of SDSF property, and two were located in the SDSF near the eastern property boundary (see map). Each effort lasted for ten minutes; distance covered was variable, depending on the in-stream terrain and fishing success. Fish and other vertebrates caught were measured, weighed and released at the end of each ten-minute effort. Fish lengths ranged from 41-276 mm TL overall.

DISCUSSION

To evaluate the age range of fish in the areas sampled, length frequency distributions were produced for each reach sampled. The fish sampled at the Amaya Creek station (Amaya Creek reach one, type B4) were treated as one group. Fish sampled on the East Branch below Ashbury Falls, at the Long Ridge Road Crossing station and at the Spanish Ranch Trail Crossing station (both in the East Branch reach two, type C1), were grouped together. Finally, fish sampled on Soquel Creek above Ashbury falls at qualitative stations 4 and 5 were treated as a separate group.

Figure 1. Length Frequency Distribution of Steelhead on Amaya Creek

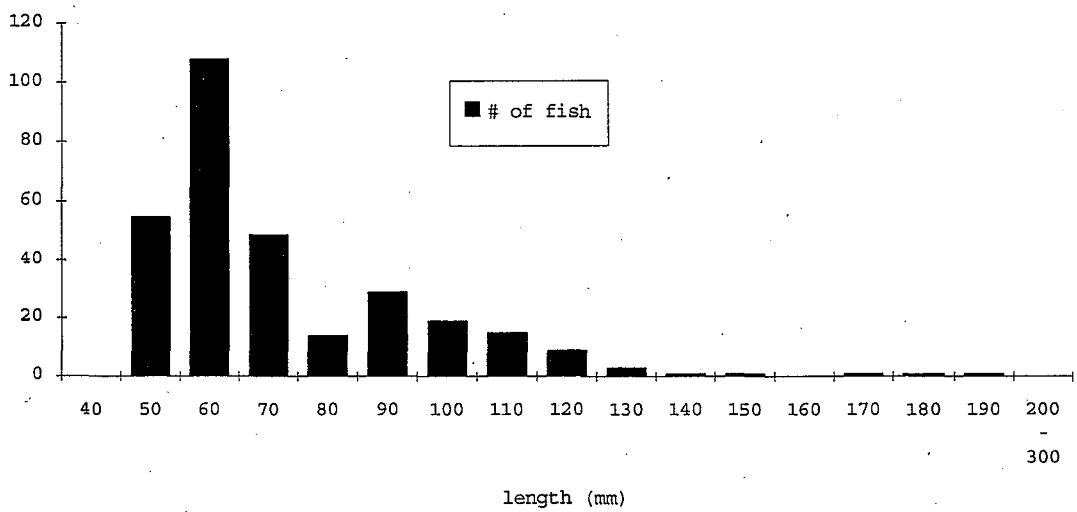
Total number of fish: 13
Population Estimate: 13
Habitat composition: 69% flatwater, 27% riffle, 4% pool



So few fish (13) were collected on Amaya Creek that it is difficult to judge the significance of the data. The length frequency distribution shows the majority of fish clustered around the young-of-the-year size class (Figure 1). This is consistent with the predominance flatwater and riffle habitat, which are the favored habitat types of young-of-the-year fish. The reason for the small sample size on Amaya Creek is unclear. It is likely that the station was not located on a representative stretch of the creek; the most recent habitat survey (SDSF, 1994) indicates that Amaya Creek as a whole is 47% riffle, 24% flatwater and 19% pool. In the station, riffles and pools were underrepresented, and flatwater was overrepresented. It is also possible that the small sample reflects the quality of habitat on Amaya Creek. Results of the habitat survey (SDSF, 1994) suggest that fish habitat in Amaya Creek is below optimum. However, as the accuracy of the station as a reflection of Amaya Creek remains unclear, it is difficult to link the results of the population and habitat surveys conclusively.

Figure 2. Length Frequency Distribution of Steelhead on the East Branch below Ashbury Falls

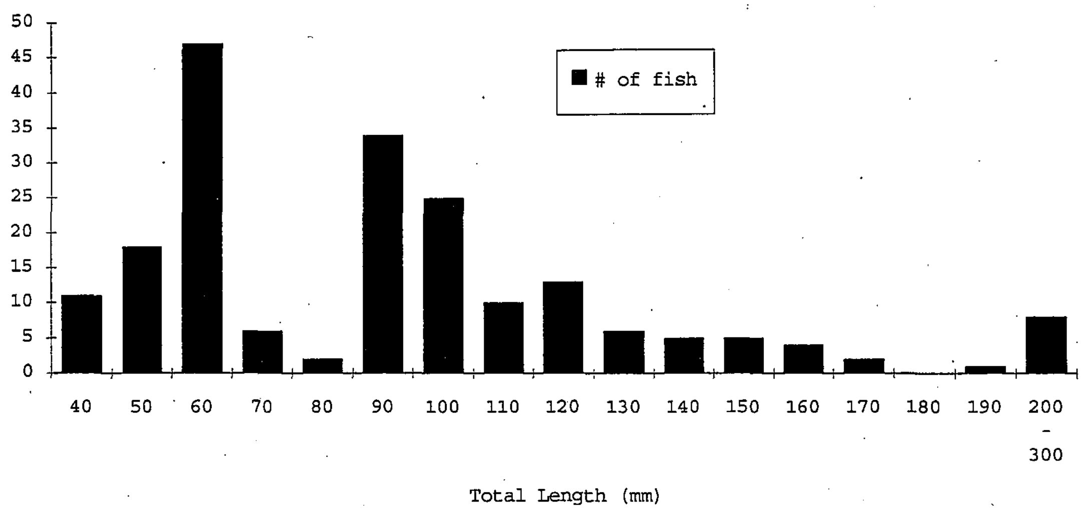
Total number of fish: 268 (combined)
Population Estimate: 284 (combined)
Habitat Composition: 77% riffle, 10% flatwater, 13% pool



The combined 306 fish that were collected on the East Branch below Ashbury Falls, fell into two general age classes; young-of-the-year and yearling fish. There were a few representatives of 2-year age class, but young-of-the-year comprised more of the sampled population than older fish (Figure 2). This composition is consistent with the habitat composition of the stations, which were predominantly riffle habitat, with some pool and flatwater habitat. The habitat composition of these stations, as derived from the habitat survey (SDSF, 1994) also did not accurately reflect the overall habitat composition of Soquel Creek. Riffle was overrepresented in the stations, and flatwater and pools were underrepresented.

Figure 3. Length Frequency Distribution of Steelhead on the East Branch Above Ashbury Falls

Total number of fish: 197 (combined)
Population Estimate: none
Habitat Composition: not available



One hundred and ninety-seven fish were collected above Ashbury falls. Both yearling and adult fish were present in significant numbers; in addition, several fish between 200-300 mm TL were present (Figure 3). The presence of this largest class suggests that members of this population may wait up to three years before migrating to the ocean, or that they may be resident. Habitat typing was not available for these areas, so it is not possible to relate the population's composition to its habitat.

CONCLUSIONS

The results of this year's population survey are intended to serve as baseline data for future surveys. At this time, only limited comparison with past electrofishing work is possible. During a 1993 survey, 3 stations were electrofished, 2 of which were sampled in 1994; just 1 of those, the station at Long Ridge Road Crossing, was sampled quantitatively. A similarly located, 338 foot long station was sampled in three passes, and a population estimate of 414 fish was derived. This estimate is considerably larger than the estimate for the same station in 1994, which was 87 fish. Even considering that the 1993 station was 38 feet longer, the estimates are disparate. Part of this discrepancy may be explained by a key difference in experimental procedure: in 1993, the site was fished over two days (block nets were left in place), whereas in 1994, the site was fished in just one day. The overnight hiatus in the 1993 sample may have affected the sampling results, but it is unlikely to account for the discrepancy. Other, unidentifiable differences in experimental procedure may also have cause the variation in sampling success. As forest management activities in the area have not changed significantly between the two years, natural causes are the most likely sources of variation. Drought conditions almost certainly caused different migration opportunities in the two years, and may well have caused these significantly different sampling results. Future surveys will make comparisons more significant.

No other sampling data from the 1994 survey can be directly compared to past survey data. Future surveys will provide bases for comparison at the other sampling sites.

SUGGESTED IMPROVEMENTS FOR FUTURE SURVEYS

Future surveys will be most useful for comparative purposes if they follow this protocol as closely as possible, incorporating the suggested changes described below:

1) Flow should be measured at all sampling stations. This will enable more detailed analysis of the data.

2) Each quantitatively sampled station should be habitat typed prior to sampling. Typing the station independent of the habitat survey of 1994 will improve the accuracy of correlations between population data and habitat data. In addition, more specific analyses of fish length as it relates to habitat type will be possible.

3) An effort to establish station 4 as a quantitative sampling station should be made.

SOURCES

Van Deventer and Platts, 1989. Microfish Data Processing Software.

```
Stream:  Amaya Creek -- sampling site 1
Species:  steelhead

Removal Pattern:    11  2  0
Total Catch              =     13
Population Estimate      =     13

Chi Square               =      0.372
Pop Est Standard Err     =      0.187
Lower Conf Interval      =     13.000
Upper Conf Interval      =     13.408

Capture Probability      =      0.867
Capt Prob Standard Err   =      0.094
Lower Conf Interval      =      0.662
Upper Conf Interval      =      1.071
```

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 12.59159 .

```
Stream:  East Branch Soquel Creek -- sampling site 2
Species:  steelhead

Removal Pattern:    64  18  4
Total Catch              =     86
Population Estimate      =     87

Chi Square               =      0.178
Pop Est Standard Err     =      1.455
Lower Conf Interval      =     86.000
Upper Conf Interval      =     89.893

Capture Probability      =      0.748
Capt Prob Standard Err   =      0.050
Lower Conf Interval      =      0.649
Upper Conf Interval      =      0.846
```

The population estimate lower confidence interval was set equal to the total catch. Actual calculated lower CI was 84.10673 .

```
Stream:  East Branch Soquel Creek -- sampling site 3
Species:  steelhead

Removal Pattern:    114  45  23
Total Catch              =    182
Population Estimate      =    197

Chi Square               =      0.504
Pop Est Standard Err     =      6.764
Lower Conf Interval      =    183.675
Upper Conf Interval      =    210.325

Capture Probability      =      0.572
Capt Prob Standard Err   =      0.046
Lower Conf Interval      =      0.482
Upper Conf Interval      =      0.663
```

ELECTROSHOCKING STATION LOCATIONS

Soquel Demonstration State Forest
(see attached map)

Sampling Site 1: Amaya Creek, trail crossing
Approximately 800-1000 ft below trail crossing.

Sampling Site 2: Soquel Creek, Long Ridge Road Crossing
Lower net position approximately 5 ft downstream from marked oak tree on southern bank, approximately 25 feet above Road Crossing.

Sampling Site 3: Soquel Creek, Spanish Ranch Trail Crossing
Lower net position approximately 17 ft upstream from middle of Spanish Ranch Trail.

Sampling Site 4: Soquel Creek, above Ashbury Falls
Hike in from Hihn's Mill Road, approximately 1.6 miles from the gate. Take abandoned skid trails down to creek. Mid-point of station where trail enters on southern bank.

Sampling Site 5: Soquel Creek, above SDSF property
Above and below bridge into SDSF from Highland Way

- 5a: above first culvert
- 5b: lower end at bottom of first pool below confluence of first trib from the North, below the confluence
- 5c: above second confluence up from 4H camp, roadside mileage paddle 1.18
- 5d: just above bridge into SDSF
- 5e: below bridge into SDSF, top of station at roadside mileage paddle 2.02

APPENDIX B: 1994 SDSF Fish Population Survey Report

APPENDIX C: Fish Population Survey Guidelines

Maximum number of fish that can be caught on pass II relative to pass I to insure less than a 10 percent error in the total population estimate.

Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II	Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II	Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II	Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II	Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II	Total Number of Fish caught on Pass I	Maximum Number of Fish that can be caught on Pass II
1 - 8	-	124 - 125	40	210 - 211	80	289 - 290	120	362 - 363	160	433 - 434	200
9 - 13	1	126 - 127	41	212 - 213	81	291 - 292	121	364 - 365	161	435 - 436	201
14 - 18	2	128 - 130	42	214 - 215	82	293	122	366 - 367	162	437	202
19 - 22	3	131 - 132	43	216 - 217	83	294 - 295	123	368 - 369	163	438 - 439	203
23 - 26	4	133 - 134	44	218 - 219	84	296 - 297	124	370	164	440 - 441	204
27 - 30	5	135 - 136	45	220 - 221	85	298 - 299	125	371 - 372	165	442	205
31 - 33	6	137 - 139	46	222 - 223	86	300 - 301	126	373 - 374	166	443 - 444	206
34 - 37	7	140 - 141	47	224 - 225	87	302 - 303	127	375 - 376	167	445 - 446	207
38 - 40	8	142 - 143	48	226 - 228	88	304 - 305	128	377 - 378	168	447 - 448	208
41 - 43	9	144 - 145	49	229	89	306 - 307	129	379	169	449	209
44 - 46	10	146 - 148	50	230 - 231	90	308	130	380 - 381	170	450 - 451	210
47 - 49	11	149 - 150	51	232 - 233	91	309 - 310	131	382 - 383	171	452 - 453	211
50 - 52	12	151 - 152	52	234 - 235	92	311 - 312	132	384 - 385	172	454	212
53 - 55	13	153 - 154	53	236 - 237	93	313 - 314	133	386	173	455 - 456	213
56 - 58	14	155 - 157	54	238 - 239	94	315 - 316	134	387 - 388	174	457 - 458	214
59 - 61	15	158 - 159	55	240 - 241	95	317 - 318	135	389 - 390	175	459 - 460	215
62 - 64	16	160 - 161	56	242 - 243	96	319 - 320	136	391 - 392	176	461	216
65 - 67	17	162 - 163	57	244 - 245	97	321	137	393 - 394	177	462 - 463	217
68 - 70	18	164 - 165	58	246 - 247	98	322 - 323	138	395	178	464 - 465	218
71 - 72	19	166 - 167	59	248 - 249	99	324 - 325	139	396 - 397	179	466	219
73 - 75	20	168 - 170	60	250 - 251	100	326 - 327	140	398 - 399	180	467 - 468	220
76 - 78	21	171 - 172	61	252 - 253	101	328 - 329	141	400 - 401	181	469 - 470	221
79 - 80	22	173 - 174	62	254 - 255	102	330 - 331	142	402	182	471 - 472	222
81 - 83	23	175 - 176	63	256 - 257	103	332	143	403 - 404	183	473	223
84 - 86	24	177 - 178	64	258 - 259	104	333 - 334	144	405 - 406	184	474 - 475	224
87 - 88	25	179 - 180	65	260 - 261	105	335 - 336	145	407 - 408	185	476 - 477	225
89 - 91	26	181 - 182	66	262 - 263	106	337 - 338	146	409	186	478	226
92 - 93	27	183 - 184	67	264 - 265	107	339 - 340	147	410 - 411	187	479 - 480	227
94 - 96	28	185 - 187	68	266 - 267	108	341 - 342	148	412 - 413	188	481 - 482	228
97 - 98	29	188 - 189	69	268 - 269	109	343	149	414 - 415	189	483	229
99 - 101	30	190 - 191	70	270 - 271	110	344 - 345	150	416	190	484 - 485	230
102 - 103	31	192 - 193	71	272	111	346 - 347	151	417 - 418	191	486 - 487	231
104 - 106	32	194 - 195	72	273 - 274	112	348 - 349	152	419 - 420	192	488 - 489	232
107 - 108	33	196 - 197	73	275 - 276	113	350 - 351	153	421 - 422	193	490	233
109 - 111	34	198 - 199	74	277 - 278	114	352	154	423	194	491 - 492	234
112 - 113	35	200 - 201	75	279 - 280	115	353 - 354	155	424 - 425	195	493 - 494	235
114 - 115	36	202 - 203	76	281 - 282	116	355 - 356	156	426 - 427	196	495	236
116 - 118	37	204 - 205	77	283 - 284	117	357 - 358	157	428 - 429	197	496 - 497	237
119 - 120	38	206 - 207	78	285 - 286	118	359 - 360	158	430	198	498 - 499	238
121 - 123	39	208 - 209	79	287 - 288	119	361	159	431 - 432	199	500	239

* Based upon the population estimation procedure described by Seber and Le Cren (1967). If the number of fish captured on Pass II exceeded the appropriate number listed in the table, Pass III was made.

FISH POPULATION DATA

1. Date: ________
   (D/M/Y)

5. Pass #: ______

2. Stream Name: ____________________________

6. Measured by: __________

3. Sampling Site: __________________________

7. Recorded by: __________

4. Description of Site:
   habitat composition:
   dominant substrate:
   cover composition:
   availability of cover:

8. Page ____ of ____

	length (mm)	weight (g)		length (mm)	weight (g)		length (mm)	weight (g)
1			21			41		
2			22			42		
3			23			43		
4			24			44		
5			25			45		
6			26			46		
7			27			47		
8			28			48		
9			29			49		
10			30			50		
11			31			51		
12			32			52		
13			33			53		
14			34			54		
15			35			55		
16			36			56		
17			37			57		
18			38			58		
19			39			59		
20			40			60		

APPENDIX D: V* Sediment Monitoring Methodology

United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Research Station**

P.O. Box 245
Berkeley
California 94701

Research Note
PSW–RN-414
July 1993

Measuring the Fraction of Pool Volume Filled with Fine Sediment

Sue Hilton **Thomas E. Lisle**

Hilton, Sue; Lisle, Thomas E. 1993. *Measuring the fraction of pool volume filled with fine sediment.* Res. Note PSW-RN-414. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 11 p.

The fraction of pool volume filled with fine sediment (usually fine sand to medium gravel) can be a useful index of the sediment supply and substrate habitat of gravel-bed channels. It can be used to evaluate and monitor channel condition and to detect and evaluate sediment sources. This fraction (V^*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. These volumes are computed for the residual portion of the pool that lies below the elevation of the downstream riffle crest. Fine-sediment thickness is measured by driving a graduated metal probe into a fine-grained deposit until the underlying coarser substrate is felt. Water depth and fine-sediment thickness are measured across transects, and volumes are computed by summing products of cross-sectional areas and distances between transects. Replicate measurements of V^* were made in 20 pools, and the variability of V^*_w, the weighted mean value of V^* for a reach, was analyzed in 12 reaches. The largest source of variability in V^* was the measurement of fine sediment volume. Topographic irregularities in pools and on riffle crests and effects of variation in discharge on measurement of riffle crest elevation also affected V^*. Ten to 20 pools are needed to estimate V^*_w in a reach, depending on acceptable error and variability between pools.

Retrieval Terms: fine sediment, pools, monitoring, sedimentation, fish habitat

Experienced hydrologists and geomorphologists can estimate the relative mobility of a streambed by looking at indicators of bedload transport, such as the freshness of bed-surface material. Another such indicator is the amount of fine sediment in pools. Pools in gravel-bed streams commonly contain deposits of fine sediment (mostly sand and gravel) that overlie a coarser substrate of coarse gravel, cobbles, or boulders. In such channels, the fraction of pool volume filled with fine sediment can be used as an index of the supply of mobile sediment. This fraction (V^*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. In a previous paper, we investigated the relationship of V^*_w, the weighted mean value of V^* for a reach, to qualitative evaluations of sediment yield in eight tributary basins of the Trinity River in northwestern California.[1] This study suggested that V^*_w could be used to evaluate sediment supply in gravel-bed channels without directly measuring sediment transport or sediment delivery from hillslopes. In one channel, V^* increased abruptly downstream of a sediment source, suggesting that V^* could be used to identify significant sediment sources.

We are conducting ongoing research on the relationship between V^*_w, sediment supply, and basin characteristics and are attempting to link V^* to habitat suitability for aquatic organisms. If this is successful, V^* could be used to simultaneously evaluate sediment supply and its effects on aquatic ecosystems. These relationships could then provide a needed link between watershed condition and fish habitat.

This paper describes a method to measure V^* and discusses factors affecting the accuracy of estimates of V^* and V^*_w.

APPLICATIONS AND LIMITATIONS

V^* can be used to evaluate and monitor channel condition and to identify and quantify effects of discrete sediment sources. There are, however, limits to the types of channels where it can be used, and care must be taken in interpreting differences in V^* between channels.

The usefulness of V^* is limited to channels in which significant volumes of fine sediment can be deposited in pools. To date, we have found that V^* can be accurately measured and results consistently interpreted in channels that have:

- a wide range in particle size between armor layers and fine sediment in pools. Sediment supply needs to include at least moderate proportions of sand and fine gravel. We have found V^* to be very low and insensitive to sediment supply in basins that are formed in basalt or competent, fine-grained metamorphic or sedimentary rocks, for example.
- stable banks of densely rooted alluvium, bedrock, or armored colluvium.
- a single thread. In braided channels, the volume and proportion of fine sediment can vary widely between anabranches and thus create wide variations in V^*.
- gradients less than about 5 percent. We

are uncertain about how V* varies inherently between step pools, which are associated with steep slopes, and bar pools, which are commonly associated with gentle slopes.

Care should be taken in interpreting differences in V^*_w between different stream channels. Knowledge of variations of V* between streams with different geologies and stream types is needed to interpret variations in V* with respect to sediment supply. For example, a value of V^*_w of 0.15 would be expected to represent high sediment supplies in basins underlain by competent metamorphic rocks, but would be considered low for basins in weathered granite. V* values can be expected to be associated with substrate conditions important to aquatic organisms, such as embeddedness or infiltration, but specific responses will depend on the community present, which will in turn depend on the natural range and variability of substrate conditions in the channel.

These problems are not encountered when monitoring changes in V^*_w over time or in using V* to evaluate sediment sources. Volumes of sediment from landslides, for example, can be easily measured from air photos or in the field, but evaluating the intensity, extent, and duration of their impacts on channels has been problematical. V^*_w measurements upstream and downstream of such sources can potentially be used to evaluate and monitor their mobile sediment inputs.

Measuring V* in large rivers has practical limitations, although pools can be sounded and fine sediments probed from tethered rafts. We have measured V* in pools as wide as 30 m and 2000 m^3 in volume. Small pools create no logistical problems, but measurement precision may need to be increased in very small pools (<1 m^3 in volume). We have measured V* in second- through fifth-order channels.

METHODS

V^*_w is estimated in a section of a stream channel by measuring the water and fine sediment volume in the residual pool in all of the pools in a study reach and then calculating the weighted average value of V* for the reach.

Time and Equipment

Two or three experienced people can measure a wadable pool in half an hour to an hour, but accurate measurement of large pools requires a raft, which takes more people and more time. The minimum equipment required is two tapes, chaining pins, and a graduated rod. The rod must be long enough to measure water depth plus fines depth in the deepest part of the pool. A rod made of one-half inch diameter stainless steel probes fine sediment deposits well without bending. Systematic sampling also requires a calculator with a random number generator or a random number table. We use a palmtop computer with a spreadsheet to choose transect locations, enter the data, and calculate V*. This reduces data processing time and provides an opportunity to catch and correct errors in the field.

Choosing a Study Reach and Identifying Pools

The general location of a study reach is set by the purpose of the study. Reaches may be located upstream and downstream of a sediment source or downstream of a watershed rehabilitation project, for example. The specific location is chosen to avoid complicating factors which might affect V* within the reach, such as intrareach sediment inputs, braided sections, or tributaries. A reach should include enough pools to provide an accurate estimate of V^*_w for the stream segment. The number of pools needed depends on the variability of V* between pools and on the desired accuracy of the estimate of V^*_w. In channels where V* does not vary greatly between pools, 10 to 15 pools are often sufficient (see Discussion).

After a study reach has been selected, the length of the reach is surveyed to identify pools to measure and determine what constitutes fine sediment in this channel. For our purposes, a measurable pool is an area of channel which (1) has a significant residual depth[2,3] (the deepest part of the pool must be at least twice as deep as the water flowing out of the pool at the downstream end); (2) has an essentially flat water surface during low flow (water surface slope <0.05 percent); and (3) includes most of the channel (it must include the thalweg and occupy at least half of the width of the low-flow channel). The specific criteria can vary, as long as they are repeatable and consistent across all reaches compared. We allow for possible variation in depositional patterns between different types of pools by measuring all pools in a reach, regardless of origin, but pool type could be a selection factor if enough pools are available. One should avoid measuring potential pools with unclear boundaries, such as long glides containing small deep areas or small deep areas in rocky channels, because it is difficult to measure such pools consistently.

What constitutes fine sediment in a channel is determined by the distribution of particle sizes and patterns of fine-sediment deposition in the channel. Fine sediment is defined as the material forming the matrix among the gravel framework of the bed material.[4] This material is commonly winnowed from areas of high shear stress, such as riffles, and deposited in pools.[1] Fine sediment in a reach is defined as material which (1) is distinctly finer than the bed surface (median particle size (D_{50}) of fine sediment approximately one tenth or less of the D_{50} of the bed surface) and (2) can be distinguished from underlying coarser sediment by probing with the rod. Deposits of fine sediment that are armored (covered by a layer of larger sediment) or densely occupied by roots of riparian plants are not considered available for transport and are not measured. In most channels, fine sediment is defined for working purposes as deposits with a D_{50} of 11 mm or less, but deposits with a D_{50} of 16 mm (medium gravel) can be measured in channels with large surface particle sizes and high transport energy.

Measuring Riffle-Crest Depth and Defining Pool Boundaries

Calculation of V* requires measuring the volume of water and fine sediment in the "residual" pool. The residual pool is defined as the portion of the pool that is deeper than the riffle crest forming the downstream lip of the pool, that is, the pool that would remain if there were negligible surface flow *(figure 1A)*.[3] The riffle crest is a high point on a longitudinal profile and usually the shallowest place at the downstream end of a pool. During low flows, when the water surface in pools is nearly flat, the riffle crest can be identified by the beginning of the riffled, more sloping water surface.

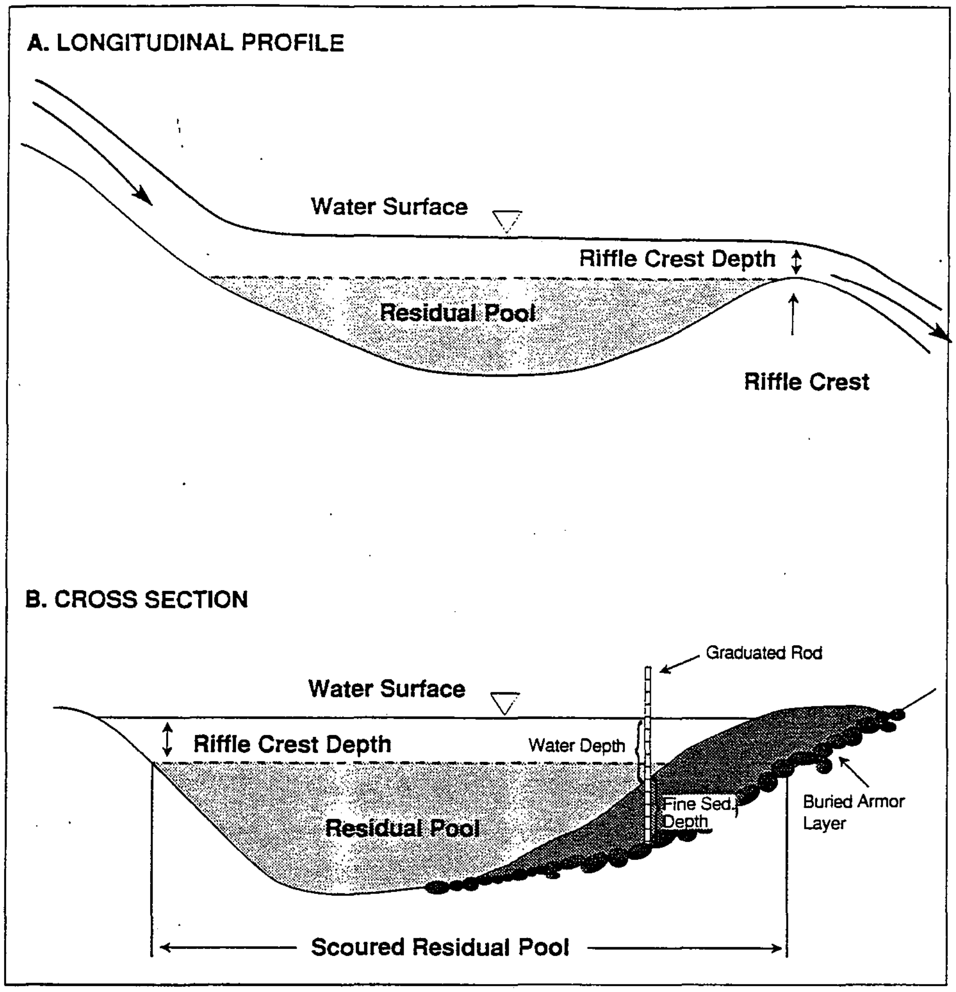


Figure 1—(A) Longitudinal profile of a pool, showing the riffle crest and the area included in the residual pool volume. (B) Cross section of a pool, showing measurement of water and fine sediment depth and volume of water and fine sediment in the scoured residual pool.

The first step in calculating V* is to measure the riffle-crest depth and define the pool boundaries. Water depth at the riffle crest is measured by taking the median of several depth measurements taken across the thalweg at the riffle crest *(figure 2)*. Because the riffle-crest depth defines the residual pool, it is important to measure it consistently. Near the riffle crest, the water surface may break in several places, discontinuously, or gradually over a distance. The riffle crest is identified as the shallowest continuous line (usually not straight) across the channel close to where the water surface becomes continuously riffled. Depths are measured across the deepest part of the flow at 5-20 evenly spaced locations along this line, depending on the width and irregularity of the measured section. To consistently measure the same section of the riffle crest, measurements are taken where we expect water to flow at minimum discharge. Thus the measured section occupies a smaller proportion of the total wetted width at high flows than at low flows. Defining and measuring the riffle crest can be confusing. Survey teams should discuss measurement locations and periodically take duplicate measurements to maintain consistency.

Water depths and fine-sediment depths are measured within the "scoured residual pool," which is the residual pool that would result if all of the fine sediment in the pool were removed. If the water surface over the pool is essentially horizontal, the boundary of the scoured residual pool is where water depth plus fine-sediment depth equals riffle-crest depth *(figure 1B)*. Where the water surface is not completely horizontal, as at the upstream ends of many pools, the boundary is where a plane at the elevation of the riffle crest would intersect the streambed with fine sediment removed (see *figure 1A)*. In a few situations, we exclude sections of stream channel which would be included in this definition. For example, a long glide extending into a pool may be excluded, even if the glide is deeper than the riffle-crest depth. Similarly, if the upstream end of the pool is a riffle that is deeper than the riffle crest, the upstream boundary of the pool is defined as where the nearly horizontal water surface would begin at a minimum flow.

Measuring Water and Fine Sediment Volume

Volumes of water and fine sediment in the residual pool are calculated from measurements of water and fine-sediment depth along a series of cross sections in the pool. The basic technique is essentially a systematic sample, with cross sections spaced evenly along the length of the pool. Zero-area cross sections are assumed at the ends of the pool. Depth-measurement points are spaced evenly across each cross section and at either end. The locations of both the cross sections and the depth-measurement points are determined from a random start. The basic system is modified in some cases to improve the accuracy of the estimate. The basic systematic sample will be described first, followed by examples of modifications for specific situations.

Basic systematic sample (figure 2).

1. Stretch a tape along the length of the pool, from the upstream end to the furthest point on the riffle crest or along the longest dimension of the pool. This tape must be straight, since bends will distort the volume calculations. If the pool is so irregular that a bend cannot be avoided, divide the pool into sections and measure each separately *(figure 3)*.

2. Draw a sketch map of the pool, showing locations of the upstream end of the pool, riffle crest, areas of fine-sediment deposition, and major features of the pool, such as logs and outcrops.

3. Decide on the number of cross sections and the distance between depth-measurement points. The appropriate sampling intensity depends on the complexity of the pool and on the accuracy required. We take from 4 to 10 cross sections in each pool and

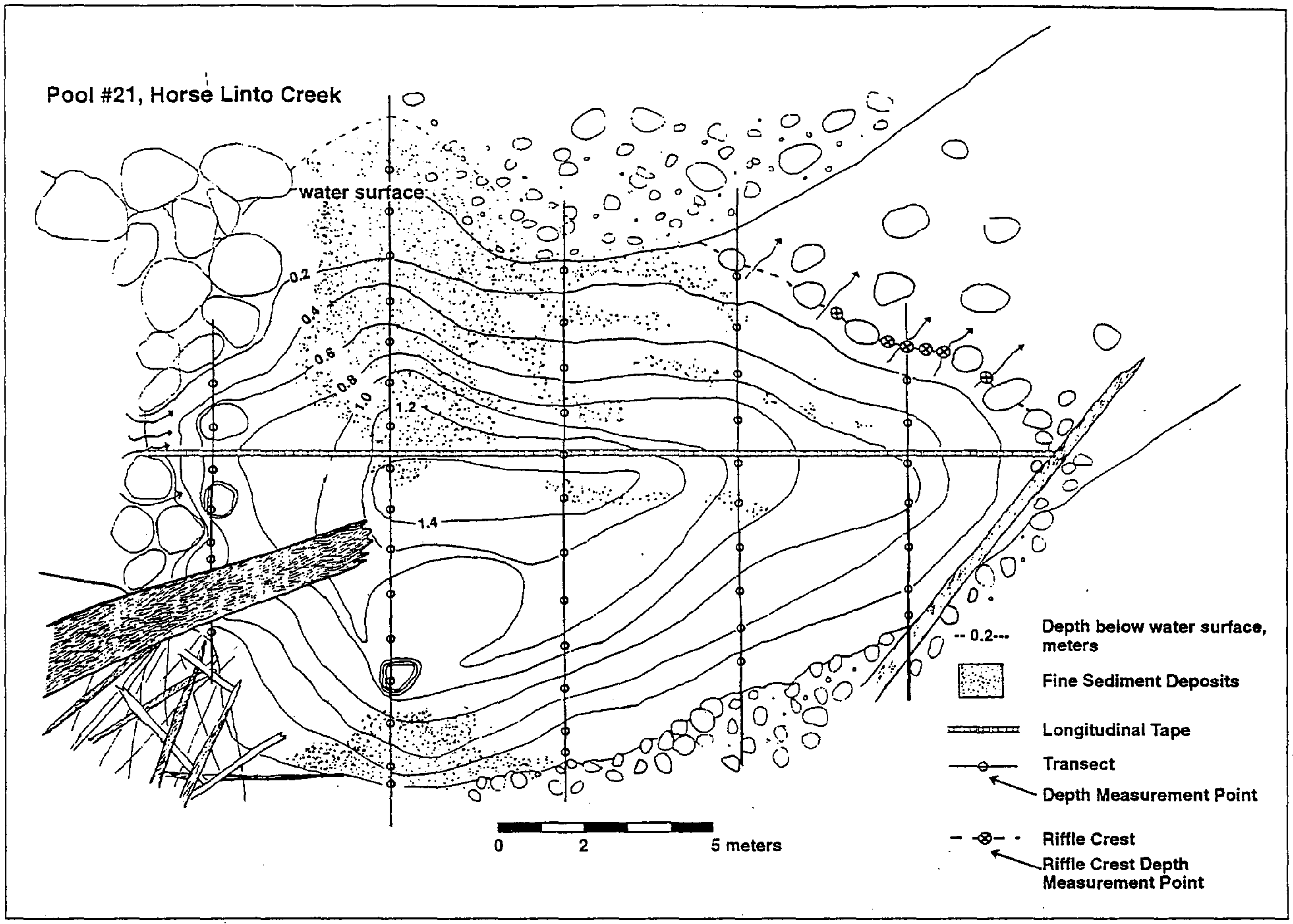


Figure 2—Pool #21, Horse Linto Creek, showing location of the longitudinal tape, transects, measurement points for water and fine sediment depth, the riffle crest, and measurement points for riffle crest depth.

set the distance between depth locations to provide 7 to 16 points across the widest cross section.

4. Determine the locations of cross sections and depth-measurement points. Divide the total length of the pool by the number of cross sections to find the distance between sections. Choose a random number between zero and this distance to locate the first cross section, and add the chosen spacing to locate the remaining sections. Choose random numbers between zero and the distance between depth-measurement points to locate the first point in from the edge of each cross section.

5. Run a tape perpendicular to the lengthwise tape at each cross-section location. Measure water depth and the thickness of any fine sediment present at each measurement point with a graduated rod. Fine-sediment depth is determined by probing with the rod until a change in resistance is felt as it strikes coarser material *(figure 1B)*. A small sledge may be useful for probing deep deposits. The cross section begins at the edge of the scoured residual pool, where water depth plus fines depth becomes greater than riffle-crest depth *(figure 1B)*. Record total water depth and fines depth at both edges of the pool, and at regular intervals across the pool as determined in step 4. If a fines deposit deep enough to be included in the scoured pool extends above the water surface, record height above the water surface as a negative water depth.

Modifications. The advantage of the basic systematic sample is that it is simple, repeatable, and statistically unbiased. The main disadvantage is that it does not use information about the pool (such as the location of fines deposits) that is available to the people taking the measurements. The basic sample can be modified in a variety of ways, from decreasing the distance between cross sections or depth-measurement points at some locations to dropping the systematic sample entirely and deliberately choosing cross-section or depth-measurement locations or both. Because deliberately chosen locations introduce potential bias, locations are chosen only when it will clearly improve the accuracy of the estimate. These are some common situations in which modifications can improve accuracy:

- In most pools, fines occupy less than one-half of the substrate area. To measure fines volume more accurately, the distance between depth measurement points is usually reduced over fines deposits, and points are added at their edges. Also, cross sections are often added to measure an area of fines more intensely or to define its upstream or downstream limits.

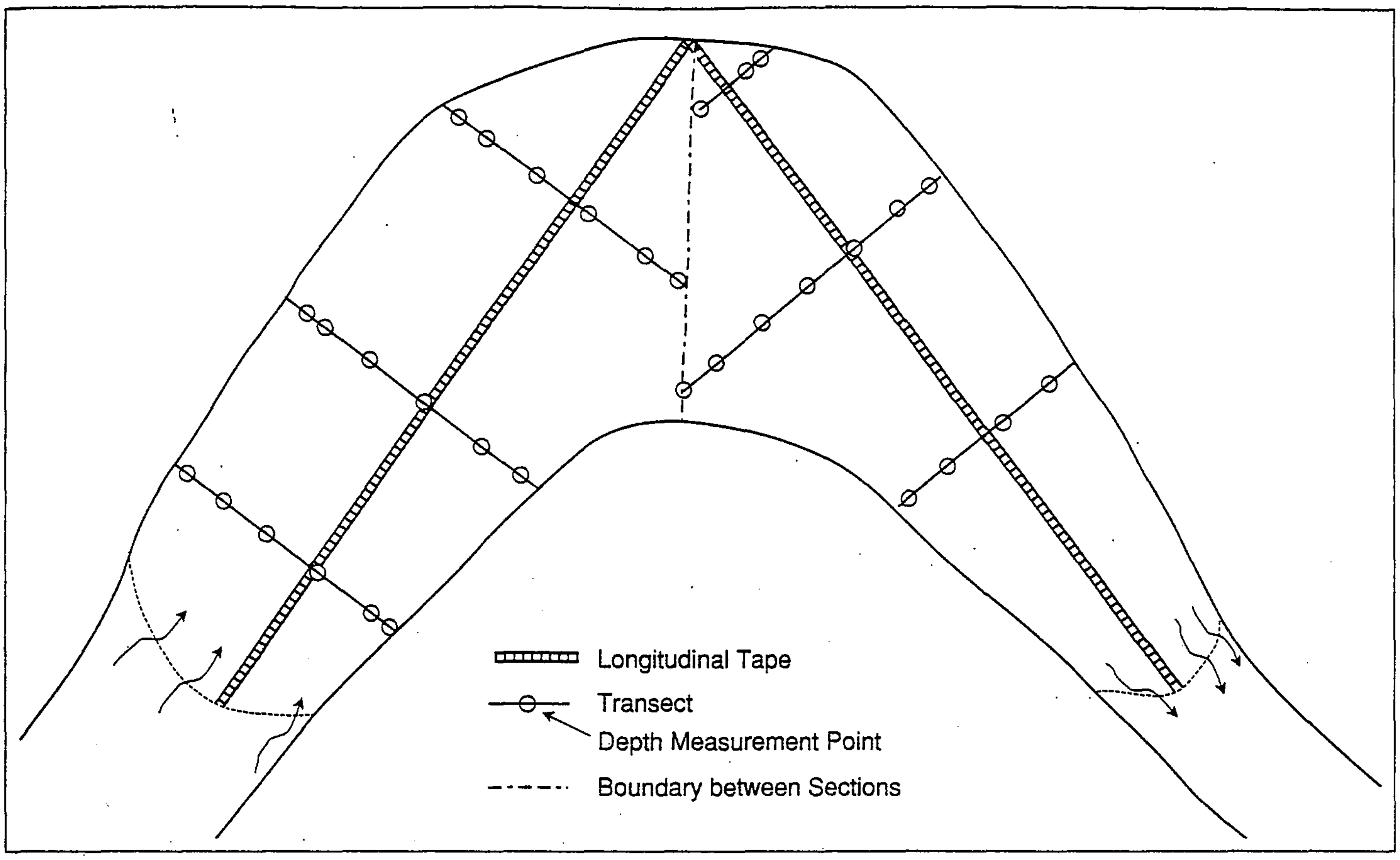


Figure 3—Measuring a pool with a bend. The longitudinal tape is strung in two straight segments, transects are located systematically along the tape, and a zero-area cross section is recorded at the location of the bend in the tape.

• If a pool has a deep, complex segment and another segment that is fairly long, simple, and shallow, the pool may be divided into two segments and the more complex segment sampled more intensely. A cross section at the boundary between segments makes the volume estimates for each more accurate.

• Cross sections or depth-measurement points or both may be added to adjust for irregularities in pool shape, such as large rocks, holes, or shoals.

• If most or all of the fines in a pool are in a few discrete deposits, their volume can be measured separately. The pool volume is measured using the basic systematic technique, as though fines in the discrete deposits were absent (fines depth measurements in the deposits are recorded as zero). The residual-pool volume of fine sediment in the deposits is then measured more intensively, and the volumes of the discrete deposits are added to the fine sediment volume measured in the rest of the pool.

Calculating V* and V^*_w

V* is calculated as follows:

1. Calculate the residual cross-sectional area (the area deeper than the depth at the riffle crest) of fines and water in each cross section.
2. Set a zero-area cross section at the upstream and downstream ends of the pool.
3. Calculate the average residual cross-sectional area of fines and water between each pair of adjacent cross sections.
4. Multiply the average cross-sectional area for each pair by the distance between them.
5. Add the volumes of the water and fine sediment in all the segments to find the totals for the pool.
6. Calculate V* for the pool:

$$V^* = \frac{\text{residual fines volume}}{\text{scoured residual pool volume}}$$

where scoured residual pool volume = residual fines volume + residual water volume.

A sample data set with detailed instructions and examples of the calculations is shown in *appendix A*. Worksheets are available to do these calculations in Lotus 1-2-3 and in SQL*Calc.

V^*_w is the average of the V*'s for all the pools in a reach weighted by the scoured pool volume of each pool. Because V* is the ratio of fines volume to scoured pool volume, the weighted mean for the reach can be simply calculated as:

$$V^*_w = \frac{\Sigma\,(\text{residual fines volume})}{\Sigma\,(\text{scoured residual pool volume})}$$

The variance of the estimated residual water volume, fines volume, and V* for individual pools may be assessed by remeasuring a sample of the pools and treating each measurement as a random sample of all possible measurements of that pool. The variability of V^*_w for the reach can also be estimated, but since V* is a ratio of two estimates (fines volume and water volume), calculating the variability of the weighted mean is complex. A formula for estimating the variability of V^*_w is in *appendix B*, along with a process for testing for significant differences in V^*_w between reaches.

ACCURACY OF THE ESTIMATES

The accuracy of the estimated value of V^*_w for a reach depends on the accuracy of the estimates of V* for each pool and on the variability of V* between pools in the reach. To find out how precise our individual pool volume measurements were, we measured variability due to sampling and measurement error by repeating measurements of several pools. We also investigated how discharge at the time of measurement affected the measured surface elevation of the residual pool and consequent values of V*. To find out how variability between pools affected V^*_w, we studied the relationship between the estimated value of V^*_w and the variability of the estimate of V^*_w in 12 reaches, eight in the Trinity River watershed and four others in northern California.

Individual Pool Estimates

Nine pools in Trinity River tributaries were measured three times each in 1990, and six of these were remeasured two or three times each in 1991. For these duplicate measurements, we kept riffle-crest depth and pool length constant and varied the starting point for the systematic sample. The standard deviation of V* ranged from 0.00 to 0.08, and increased slightly with V*. Coefficients of variation ranged from 0 to 170 percent, with the higher values concentrated at very low values of V* *(figure 4)*. The coefficient of variation of V* in a pool was highly correlated to that of the fine sediment volume in that pool (r = 0.995). *Figure 4* also includes the coefficients of variation for five pools in the Salmon River, California, which were measured three times each in 1991. These measurements were taken a week apart, by different people, and riffle-crest depth and pool length varied somewhat between measurements. The standard deviations and coefficients of variation of those pools were similar to those of the other replicate measurements.

Effect of Discharge on V*

Because we measure only within residual pools, the measured water and fine-sediment volumes (and thus V*) should not vary with discharge. If the riffle crest is always measured in the same place, the riffle-crest depth will increase exactly as much as the water surface of the pool rises, the elevation of the surface of the residual pool (riffle-crest elevation) will be constant, and the same volume will be measured at any discharge. However, because locating the riffle crest and selecting the section to measure are somewhat subjective, there is some potential for error. Systematic errors could occur if the measured riffle-crest elevation is consistently affected by discharge and if V* is consistently affected by riffle-crest elevation. To determine whether discharge affects riffle-crest elevation, we measured riffle-crest elevation (water-surface elevation minus the measured riffle-crest depth) at three pools in Jacoby Creek at four different flow levels. Elevations were measured at extremely low base flows, normal summer base flows, and flows significantly above summer base flows. To find out whether riffle-crest elevation affects V*, V*'s calculated at different riffle-crest depths were compared for sample pools from five creeks in northern California.

Measured riffle-crest elevations in Jacoby Creek tended to be higher at low flows than at high flows, possibly because the width of the minimum flow channel was underestimated at high flows. Riffle-crest elevations did change less than water-surface elevations, however. Maximum changes in water-surface elevation ranged from 0.10 to 0.20 m, whereas changes in riffle-crest elevation ranged from 0.01 to 0.07 m. Maximum changes in residual elevation were equivalent to 10 percent, 25 percent, and 70 percent of the riffle-crest depth of the respective pools at moderately low flows.

To evaluate the effect of an error of this magnitude in riffle-crest elevation on V*, we calculated V* using a riffle-crest depth equivalent to 150 percent of the original value (measured at moderately low flows) in 19 pools. Original values of V* ranged from 0.01 to 0.62. The deeper riffle-crest depths resulted in smaller residual pools, which had higher V* values in 18 of the 19 cases. The mean percent change in V* was 13 percent (16 percent if the negative change was omitted), which corresponded to a mean absolute change in V* of 0.05.

Variability in V^*_w

We calculated the standard error of the estimate of V^*_w for all of the reaches we measured using the formula in *appendix B*. We then modified the formula to predict the number of samples (pools) required to

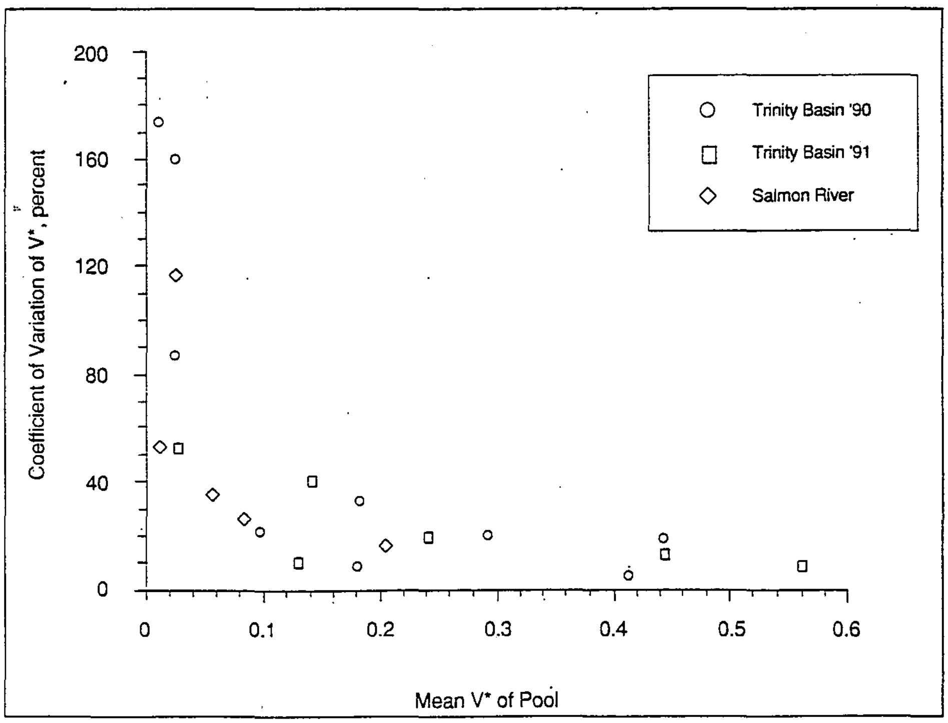


Figure 4—Variability of the estimate of V*, from multiple measurements of V* on pools in Trinity River tributaries in 1990 and 1991 and in the South Fork Salmon River in 1991. The coefficient of variation is the percentage ratio of the standard error of the mean to the mean value of V* for each set of measurements.

achieve a standard error of 20 percent of V^*_w for each reach. The standard errors of our reaches, each of which included 10 to 20 pools, ranged from 0.01 to 0.06 and averaged 17 percent of the value of V^*_w. The calculated sample size necessary to obtain a 20 percent error in V^*_w ranged from 4 to 26 pools and generally decreased as V^*_w increased. Exceptions were reaches in Grouse Creek, which had extremely irregular pools due to the presence of very large boulders, and in North Fork Caspar Creek, which had irregular pools caused by large woody debris. These two reaches had high standard errors and required higher sample sizes.

DISCUSSION

The main factor affecting the variability of the estimate of V* for a pool seems to be the amount of fines in the pool. In pools with moderate to high values of V* (V* >0.10), most (80 percent) of the standard deviations were less than 20 percent of the mean V* for the pool. In pools with lower V* values, the standard deviations ranged up to 170 percent of V*. Although it is not practical to expect the same percent errors in these pools as in those with higher V* values (because a small percent of a small number is a very small number), it may still be important to measure V* in these pools more precisely than in pools with a higher proportion of fine sediment. Error in V* was strongly correlated with error in fines-volume measurement, and fine sediment does tend to be measured less intensively when it occupies a small proportion of the area of the pool. Therefore, we strongly recommend increasing sampling intensity in areas of fines or measuring fine-sediment deposits separately, or both, particularly where fine-sediment deposits occupy a small proportion of the surface area of the pool or when it is important to measure low values of V* accurately.

Estimates of the maximum possible error in V* due to variations in discharge (13-16 percent of V* measured at moderately low flow) were slightly less than the 18 percent average measurement error for replicate measurements at a constant discharge. However, measurement error from systematic samples with a random start is random, whereas errors due to changes in water depth appear to be consistent and thus have the potential to bias V^*_w. We recommend measuring at moderately low flows. Riffle-crest depths can be difficult to measure accurately at very low flows when the pattern of the flow is affected by surface rocks. At moderately high flows the water surface over a pool is likely to slope appreciably and affect pool volume measurements. For monitoring over time, comparisons will be more accurate if V^*_w is measured at a consistent stage or discharge. Similarly, comparisons between reaches will be more reliable if all reaches are measured at nearly the same relative flow. If this is not possible, allowance should be made for the possibility that values of V^*_w measured at high base flow could be elevated relative to those measured at low flow.

Our estimates of the variability of V^*_w include the effects of measurement errors in V* but do not include any possible bias due to variations in discharge, since all pools in a reach were measured at approximately the same discharge. The desired standard error of V^*_w depends on the precision required to detect changes in a reach, deviations from a reference value, or differences between reaches. We found that the standard errors from measuring 10-20 pools per reach enabled us to distinguish fairly well between reaches, and the sample size calculations indicated that fewer pools would probably have been enough in most reaches. The calculated sample size *(figure 5)* is not necessarily the number of pools that should be measured in each reach, since the percent error in V^*_w needed to distinguish between reaches will depend on both the value of V^*_w (a 20 percent error is a large range of V^*_w values when V^*_w is high and a small range when V^*_w is small) and on the closeness of the values being compared. The sample size calculation does, however, indicate the relative sampling intensity required to be able to measure reaches with high standard errors at the same precision as reaches with lower variability between pools. We recommend evaluating the irregularity of the pools and the variation in V* before and during data collection in a reach. If all of the pools in a reach have similar values of V*, then differences between the estimates of V* caused by measurement error could have a significant effect on the variance of the estimate of V^*_w, and V^*_w can be best estimated by measuring a few (6-10) pools accurately. For most reaches we recommend measuring 10-15 pools, and if the value of V* varies widely between pools, the best strategy might be to measure as many pools as possible (20 or more), perhaps with less sampling intensity on each. If V* is highly variable but the number of pools available

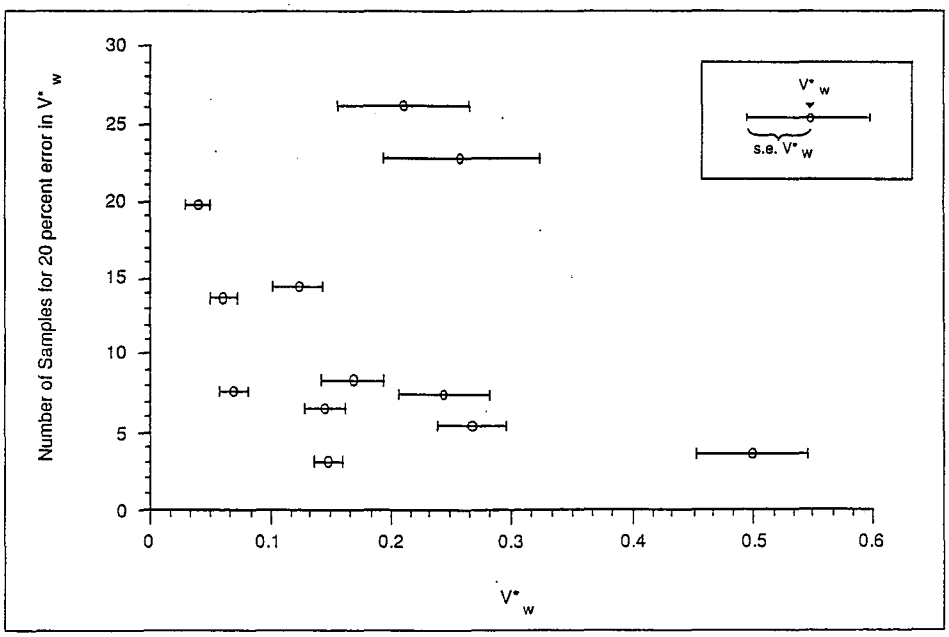


Figure 5—Predicted sample sizes necessary to limit the error in V^*_w to 20 percent of the value of V^*_w for that reach, calculated for 12 reaches. Our estimate of V^*_w for each reach is shown with our standard error of the estimate for that reach, which was based on 10-20 pools.

in the reach is limited (by sediment sources, changes in slope, etc.), putting more effort into sampling each pool will at least reduce the measurement-error component of the total variability. If the objective is to monitor a reach over time, and if the structure of the pools in a reach is fairly stable, accurate measurements of a few major pools at approximately the same discharge each year may give the best information.

SUMMARY OF RECOMMENDATIONS

To minimize variability of the estimates and eliminate potential bias, we make the following recommendations:

Fine Sediment Measurements

- When fine-sediment deposits occupy a third or less of the pool substrate area, increase measurement intensity in fine-sediment deposits, either by decreasing the distance between depth-measurement points or by making separate measurements of deposits.

Discharge Levels

- Measure all pools at moderately low flows.
- If a reach is being monitored over time, measure at approximately the same discharge each year.
- If reaches are being compared, measure all reaches at approximately the same relative flow.

Sample Size

- If all pools in a reach have similar values of V*, measure 6-10 pools relatively intensively.
- If V* varies somewhat (V* for all pools is within 20-30 percent of the mean), measure 10-15 pools.
- If V* is highly variable (some V*'s of 0.4 or more and others 0.1 or less), measure as many pools as possible, up to 20 or so.
- If the objective is to monitor changes over time in a single reach, and if the pools in the reach are structurally stable, intensive measurement of a few pools (4-5 minimum) may minimize variability and provide additional information about changes in individual pools.

APPENDIX A

Calculating Residual Pool Water Volume, Fine-Sediment Volume, and V*

Follow these basic steps to compute residual-water and fine-sediment volumes for a pool:

1. Calculate cross-sectional areas of the water and fine sediment in the residual pool at each cross section.
2. Assume a zero-area cross section at the beginning and end of the pool. Calculate water and sediment volumes in cells between each pair of adjacent cross sections, including the zero-area cross sections at the endpoints.
3. Sum residual-water and fine-sediment volumes for all of the cells to compute total volumes.

The following example of the calculations uses the data from a very small pool. In this example, d = water depth, d_{rc} = riffle-crest depth, and y_f = fine-sediment thickness. These are the data:

riffle-crest depth (d_{rc}) = 0.10 m; total length of pool = 12.0 m

cross section #1 at 2.4 m

distance (m)	0	0.5	1.5	2.5	2.7
d (m)	0.10	0.50	0.88	0.40	0.10
y_f (m)	0	0	0.02	0.02	0

cross section #2 at 6.4 m

distance (m)	0	1	2	3	4	5	6	6.2
d (m)	0.06	0.62	0.74	1.12	0.96	0.70	0.56	0.10
y_f (m)	0.04	0.10	0.02	0.01	0	0	0	0

cross section #3 at 10.4 m

distance (m)	0	0.8	1.8	2.8	3.8	4.6
d (m)	-0.02	0.08	1.08	1.14	0.94	0.10
y_f (m)	0.12	0.10	0.14	0.06	0.04	0

The first step is to compute depths of the water and fines in the residual pool. The residual water depth, d_r, is the water depth minus the riffle crest depth. The residual fine-sediment thickness, y_{rf}, is the thickness of the fine sediment below the riffle crest *(figure 1)*. If the water depth at any location is less than the riffle crest depth, the fines thickness at that location is reduced by a corresponding amount. That is, $d_r = d - d_{rc}$ and IF $d < d_{rc}$, THEN $y_{rf} = y_f - (d_{rc} - d)$, ELSE $y_{rf} = y_f$. After these calculations, the data look like this:

cross section #1

distance (m)	0	0.5	1.5	2.5	2.7
d_r (m)	0	0.40	0.78	0.30	0
y_{rf} (m)	0	0	0.02	0.02	0

cross section #2

distance (m)	0	1	2	3	4	5	6	6.2
d_r (m)	-0.04	0.52	0.64	1.02	0.86	0.60	0.46	0
y_{rf} (m)	0	0.10	0.02	0.01	0	0	0	0

cross section #3

distance (m)	0	0.8	1.8	2.8	3.8	4.6
d_r (m)	-0.12	-0.02	0.98	1.04	0.84	0
y_{rf} (m)	0	0.08	0.14	0.06	0.04	0

The next step is to compute cross-sectional areas of water and fine sediment. We start by calculating the width w_i, average residual depth $(d_r)_i$, and average fine-sediment thickness $(y_{rf})_i$ of each segment of the cross section (between two adjacent measurement points).

cross section #1

segment number	1	2	3	4
w_i (m)	0.5	1	1	0.2
$(d_r)_i$ (m)	0.20	0.59	0.54	0.15
$(y_{rf})_i$ (m)	0	0.01	0.02	0.01

cross section #2

segment number	1	2	3	4	5	6	7
w_i (m)	1	1	1	1	1	1	0.2
$(d_r)_i$ (m)	0.24	0.58	0.83	0.94	0.73	0.53	0.23
$(y_{rf})_i$ (m)	0.05	0.06	0.015	0.005	0	0	0

cross section #3

segment number	1	2	3	4	5
w_i (m)	0.8	1	1	1	0.8
$(d_r)_i$ (m)	-0.07	0.48	1.01	0.94	0.42
$(y_{rf})_i$ (m)	0.04	0.11	0.10	0.05	0.02

In each segment, the cross-sectional area of residual water $(a_r)_i$ equals $(d_r)_i \times w_i$, and cross-sectional area of fine sediment $(a_{rf})_i$ equals $(y_{rf})_i \times w_i$. Negative average water depths are set equal to zero. This gives us:

cross section #1

segment number	1	2	3	4
$(a_r)_i$ (m^2)	0.10	0.59	0.54	0.03
$(a_{rf})_i$ (m^2)	0	0.01	0.02	0.002

cross section #2

segment number	1	2	3	4	5	6	7
$(a_r)_i$ (m^2)	0.24	0.58	0.83	0.94	0.73	0.53	0.046
$(a_{rf})_i$ (m^2)	0.05	0.06	0.015	0.005	0	0	0

cross section #3

segment number	1	2	3	4	5
$(a_r)_i$ (m^2)	0	0.48	1.01	0.94	0.336
$(a_{rf})_i$ (m^2)	0.032	0.11	0.10	0.05	0.016

The total cross-sectional area of residual water, A_r, and fine sediment, A_{rf}, of each cross section equals the sum of the corresponding segment areas. Cross sections are added to upstream and downstream ends of the pool and given areas of zero.

cross-section #	0	1	2	3	4
location (m downstream)	0	2.4	6.4	10.4	12
A_r (m^2)	0	1.26	3.90	2.77	0
A_{rf} (m^2)	0	0.032	0.130	0.308	0

To compute the water and fine sediment volume in each cell of the pool, between each two adjacent cross sections, we calculate the average cross-sectional areas of residual water $(A_r)_j$ and fine sediment $(A_{rf})_j$ and the length (l_j) for each cell. The cell in the upstream end of the pool, for example, has an average residual area equal to one-half of the area of the first cross section downstream.

cell number	1	2	3	4
l_j (m)	2.4	4.0	4.0	1.6
$(A_r)_j$ (m^2)	0.63	2.58	3.33	1.38
$(A_{rf})_j$ (m^2)	0.016	0.081	0.219	0.154

The volumes for each cell, $(V_r)_j$ and $(V_{rf})_j$, are the average areas times the length, and the total for the pool is the sum of the volumes of all the cells.

cell number	1	2	3	4	total
$(V_r)_j$ (m^3)	1.5	10.3	13.3	2.2	27.4
$(V_{rf})_j$ (m^3)	0.04	0.32	0.88	0.25	1.48

Finally we calculate V* as: $\dfrac{\text{total fines volume}}{(\text{total fines} + \text{total residual pool volume})} = 0.051$

and we're done!

APPENDIX B

Estimating the Variance of the Estimate of V^*_w

The formula we used for estimating the variance of V^*_w was developed using the Delta method[5] for estimating the variance of a variable that is a function of other variables. The variance of V^*_w for a reach is calculated as:

$$\widehat{Var}\left(V_w^*\right) \equiv n\left(\sum_{i=1}^{n} f_i + \sum_{i=1}^{n} w_i\right)^{-4}\left[\left(\left(\sum_{i=1}^{n} f_i\right)^2 \sigma_w^2 + \left(\sum_{i=1}^{n} w_i\right)^2 \sigma_f^2\right) - 2\sum_{i=1}^{n} f_i \sum_{i=1}^{n} w_i\left(\operatorname{cov}(f,w)\right)\right]$$

where f_i is the fines volume and w_i is the residual pool water volume of the ith pool in the reach, and $\widehat{cov}\ (f,w)$ is the covariance of the fines volume and the water volume in the reach. The covariance is calculated as:

$$\widehat{cov}\ (f,w) = \frac{\sum_{i=1}^{n}\left(f_i - \bar{f}\right)\left(w_i - \bar{w}\right)}{n-1}$$

The covariance can be obtained from many statistical programs by printing a variance-covariance matrix.

The calculated variance can be used to test for significant differences in V^*_w between two reaches by assuming that the test statistic,

$$\frac{V_{w1}^* - V_{w2}^*}{\sqrt{\widehat{Var}\left(V_{w1}^*\right) + \widehat{Var}\left(V_{w2}^*\right)}},$$

has a standard normal distribution.

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APPENDIX F: Streambank Revegetation Guidelines

VEGETATIVE EROSION CONTROL PLANTINGS -- WOODY CUTTINGS

(Modified for Santa Cruz County)

SCOPE

This work shall consist of preparing the area for treatment, furnishing, and placing the woody cutting in the areas specified on the drawings.

MATERIALS

Cuttings

Woody cuttings shall be made from healthy green plants. Stem or branch cuttings of softwood, hardwood, or firm wood should be taken whenever possible from plants that are native to the locality or grown on similar sites. Cuttings shall be made during the dormant period.

Cuts shall be made clean with sharp tools. The butt end of the stem shall be a slant cut and the tip end shall be cut square across the stem. Any leaves shall be removed immediately after the cutting has been taken.

The diameter of the cutting shall not be more than two (2) inches at the butt end nor smaller than one-quarter (1/4) inch at the tip.

The length of the cuttings shall be as follows:

A. Deep plantings made at three (3) foot depths shall have a minimum cutting length of four (4) feet.

B. Plantings made in soils moist throughout the year shall have a minimum cutting length of one and one-half (1 1/2) feet.

   Cuttings shall not be allowed to dry and shall be no more than five (5) days old when planted. If the cuttings are not planted the same day they are cut, the method of keeping cuttings moist shall be approved.

PLANT TYPES

<u>Method 1</u> -- Willow (Salix sp.)
<u>Method 2</u> -- Cottonwood (Populus sp.)
<u>Method 3</u> -- Box Elder (Acer negundo)
<u>Method 4</u> -- Elderberry (Sambucus sp.)

PLANTING REQUIREMENTS

Wood cuttings shall be planted in one or more rows. Plantings shall be spaced three (3) feet apart in the row. In multiple row plantings, spacing between rows shall be three (3) feet and staggered with respect to those in adjacent rows.

Cuttings should be planted in prepared holes or "V" furrows to avoid striping the bark, especially in rocky or hard soils. Prepared holes or furrows may not be needed if the soil is saturated.

Cuttings shall be placed in the soil with the butt end in a downward position.

All cuttings shall have one (1) foot or at least two (2) nodes above the ground level.

Method 1

Plantings shall be placed into the soil to a depth of at least three (3) feet. However, if due to some physical condition in the soil this planting depth cannot be attained, the cuttings shall be set with three-fourths (3/4) of its length in the ground. Plantings shall be protected from damage and soil kept moist in the the lower two (2) feet of the planting depth for the duration of the contract.

Method 2

Planting depth for soils that are moist throughout the year shall be one (1) foot deep. However, if due to some physical condition in the soil this planting depth cannot be attained, the cuttings shall be set with three-fourths (3/4) of its length in the ground.

SANTA CRUZ COUNTY RESOURCE CONSERVATION DISTRICT

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APPENDIX G: Stream Inventory Sheet

STREAM INVENTORY SHEET

Obs#

Stream Reach
Observer
Location T. R. Sect Quad

Date
R# Ph#

PROBLEM: logjam__ landslide__ culvert__ dam__
bridge__ waterfall__ rip-rap__ road__
cement__ rockfall __ gully __
other ______________________________

IMPACTS: fish barrier Y/N/P/UN
diversion Y/N/P
endangered structure Y/N ________
assoc w/jam__ slide___ road___ other___

JAM: #trees___ dia___ #root wads___ dia___
#logs ___ dia___ bran/debris vol___

SLIDE: slope___% colluv/soil/fill/bdrx
remain vol___ vegetation cover___%
active sediment source high/mod/low

DESCRIP: Vol: wid__ x len__ x hgt__ = _____CUFT
Sed Wdge Y/N len___x hgt___ = _____CUFT
Approx Age ___ Stable Y/N/UN

Water flows thru/over/around feature.
Water Jump vert___ horiz___ Pool Y/N depth___

CAUSE + DESCRIPTION ______________________________

Substrate Dim ____________
VEG: Red-fir/alder/willow/brush/oak/______

****

REMOVAL Y/N PRIORITY: high/mod/low
Work Crew CYA___ #days___ Contract___ Other___
ACCESS ROUTE ______________________________

Reviewed By___